Application Of Mobile Digital Communications In Law Enforcement

—An Introductory Planning Guide

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FOREWORD

The public safety planner who wants to bring the results of advanced technology to the service of his department - very specifically, to evaluate the possibilities of applying digital techniques and equipment to police communications, command, and control functions - faces a difficult problem.

A number of possible needs in the modern, expanding, and heavily burdened law enforcement communications system may be met by various features of digital communications. But the analysis of these applications, the design of a system to use them, and the analysis of performance, costs, and competing characteristics are rather difficult technical tasks. The market displays a variety of equipments, some already in service, some in production, some still being developed. Although much information exists on the abstract problem, on individual experiences, and on existing or projected equipments, there has been little or no guidance through the maze of needs and offerings.

This document is intended to provide an initial answer to that problem. It is the product of an effort sponsored by the National Criminal Justice Information and Statistics Service of the Law Enforcement Assistance Administration (LEAA), United States Department of Justice, as a part of the LEAA's mission of giving technical assistance to state and local law enforcement agencies. The work was carried out by Caltech's Jet Propulsion Laboratory, which has developed and operated communications and control systems for federal agencies and has studied and developed a number of technical systems in the civil field. The document is based in part on other studies performed for LEAA and various state and local agencies.

The guidelines are addressed to the local law enforcement planner who must face practical working problems, who must decide whether it is worthwhile to redesign his department's communications in order to speed up transmissions and improve information access, and to increase the efficiency and save the time of his officers in the field, balanced against the technical difficulties and costs associated with implementing digital communications systems. Working out these problems is not an easy task. But we believe that facing the problems is imperative, and examining them is worthwhile.

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ABSTRACT

A set of planning guidelines for the application of digital communications techniques to law enforcement use is presented in brief. Some essential characteristics of digital techniques and their applications are outlined, as are some principles of system analysis, evaluation, and planning. Requirements analysis, system concept design, implementation planning, and performance and cost modeling are described and demonstrated with respect to this application problem. Information on law enforcement digital communications systems and equipment and a list of vendor sources are given in appendices.

1. INTRODUCTION

1.1 The Growing Interest in Digital Communications

For several years there has been a growing interest within the law enforcement community in supplementing existing communications systems by some kind of digital communications. A few law enforcement agencies have implemented systems of digital communications, several more are planning to do so, and nearly all are interested to some extent. The Law Enforcement Assistance Administration has a strong interest in this field and, through its technical assistance programs, has supported a number of studies and test programs.(See also References 1-5 and Table 1.)

There are two major reasons for the interest in digital communications. The most compelling one is the crowding of the radio channels available for law enforcement mobile communications, resulting in delays, poor quality, or both. If the routine messages that occupy a large portion of the total channel time can be transmitted in digital form they will require much less time for transmission and will be less subject to distortion or error. A second major reason for the interest in digital communications is that many law enforcement crime information files are now computerized, and a field unit equipped with a digital communication capability can access these data bases directly if a suitable switcher is provided at the base station; this greatly facilitates data base inquiries, and contributes to enhanced officer safety as well as increased "hit" rates.

While the potential benefits of digital communications systems are significant, possible drawbacks also must be recognized. Unit costs of digital equipments are relatively high at present, and the need for specialized maintenance over the life of the system may be a burden to the user agency; digital transmissions over existing voice channels may degrade the voice qualities of the channel, requiring special squelch techniques; and message transmissions are subject to errors in difficult telecommunications environments, such that total repetition of the messages or advanced error detection schemes are needed. Finally, installing digital terminals in already crowded patrol units must be evaluated in terms of officer convenience and safety. Weighing these advantages and disadvantages of digital communications is the challenge confronting the planner.

1.2 Status of Digital Communications Programs

Several law enforcement agencies that have installed digital communications or computer-aided dispatch systems were contacted to discuss their experiences with system design and implementation, and the impact on operational effectiveness. Use of these systems in fully operational environments is quite limited since the first test units were put into the field in 1972, and, with a few exceptions, operational systems went on line in 1974.

Table 1. Characteristics of Several MDT and CAD Installations

	Agency								
	Kansas City PD	San Francisco PD	Oakland PD	Palm Beach SO	Cleveland PD	Minneapolis PD	Huntington Beach PD	Seattle PD	Glendale PD
Population (000's)	503	720	360	150	741	435	150	525	135
Calls for service, per year[1] (000's)	465	438	256	35	730	190	57	525	50
Patrol units[2]	150	52	45	36	138	45	22	153	19
Officers per unit	1	1	1 - 2	1	2	2	1	1	1
MDT or CAD	MDT	Both	MDT	Both	MDT	MDT	Both	CAD	CAD
MDT utilization									
MDT capability	Query	Query	Query	Query Status Dispatch	Query	Query	Dispatch	None	None
Patrol units with MDT	14	5	27	30	40	25	22	0	0
Queries per MDT per hour	4.8	NA	2.0	1.9	6	2	0.4	NA	NA
Increase in queries with MDT	X 4.5	NA	X 5	X 10	X 3.5	X 10	NA	NA	NA
Communications									
No. of switchboard operators	9	8	10	2	16	16	1	6	2
No. of dispatchers		8	2	2	7	7	2	4	2
No. of RF channels	5	4	2	2	6	5	1	6	2
No. of digital channels	1	2	1	1	2	1	1	0	0
No. of units per channel	65	18	30	18	40	45	30	50	19

[1] Dispatches per year.
[2] Number of units deployed during peak period.

The characteristics of several digital communications installations and computer-aided dispatch systems are given in Table 1. Considerable variation in the relative size and operating characteristics of the nine agencies is noted, although differences are much less when comparisons are made on a per capita basis.

Several observations can be made regarding the use of mobile digital terminals. First, use of MDT's by law enforcement agencies is in its infancy; less than 1 percent of the total patrol fleet is equipped with these devices, and operational experience is limited to less than 1 year in most cases. About 2 to 3 percent of all patrol fleets will be so equipped by the end of 1975. A wide variance in use rates is observed, from 1.9 to 6 queries per MDT per hour. Many factors contribute to this variance, such as relative number of calls for service, patrol units per capita, crime rate, one-man versus two-man patrols, and agency policies regulating the conditions under which data base queries are made. Some agencies, for example, direct *all* queries to the NCIC as well as to local and state crime information files; others limit queries to files within the state. Extensive vehicle checks are encouraged by some agencies, and restricted by others. An important conclusion, however, is the relatively large increase in queries demonstrated by all agencies: from a minimum of 250 percent to over 1000 percent. The average increase for all agencies is 560 percent. Agency planners must be aware of this trend and its impact on communication channel loading.

No optimum strategy for incorporating digital communications or computer-aided dispatch systems was discovered. Generally, agencies were able to install MDT systems without undue difficulty and experienced ready acceptance by field personnel. Computer-aided dispatch has a greater impact on operational procedures and requires more elaborate planning and personnel indoctrination. As equipments, software, and displays become more standardized, changeover to CAD should be easier to carry out and less expensive. Field experience with both of these important innovations over the next few years will be invaluable to planners who are considering upgrades to their own facilities.

1.3 The Guidelines Manual

The purpose of this introductory guidelines document is to assist law enforcement agencies in selecting, evaluating and developing operational plans for digital communications equipments. The document discusses potential applications, gives a brief review of system and equipment descriptions, and presents a planning methodology for:

(1) Establishing system requirements

(2) Developing system concepts

(3) Preparing an implementation plan, including costs and schedules

(4) Performing a cost/benefits analysis

The chapter on planning methodology contains several examples of system implementations and costs, and includes a computer simulation of a police patrol command and control system showing patrol unit utilization, communication channel loading, dispatcher loading, and other performance parameters required to assess potential system upgrades. System simulations are shown for a voice-only manual system, and for a digital system to demonstrate the effects of digital transmissions.

Equipment descriptions are presented in the appendices and can be consulted by the planner for details on specific system elements. A list of vendor contacts is included for the reader's convenience.

A final word to the planner. While digital communications can accomplish the immediate goal of reducing (but not eliminating) overloads on voice RF networks, it is becoming apparent that modifications must be made to the command and control system if the agency wishes to exploit the full capabilities offered by digital techniques: status reporting, direct query of information files by field personnel using mobile digital terminals, computer-aided dispatching, and other functions. For the agency considering digital communications, it is perhaps best to install functions one at a time, status reporting first because it is the easiest and least costly to implement, then full text transmission for dispatch operations and reporting, and, after these basic functions are fully operational, an automated data base query capability, which requires a more sophisticated message handling device at the base station. This evolutionary approach has been followed by several agencies with good results and has gained acceptance in many instances where changeover to a multi-function system in one upgrade may have jeopardized the program.

The capability to evaluate and plan for these new technologies must be developed at an early date because, in the aggregate, digital communications properly supported by advanced command and control systems, offer a great potential for improved law enforcement operations.

2. DIGITAL COMMUNICATIONS FOR LAW ENFORCEMENT

2.1 Characteristics of Digital Communications

For purposes of this discussion, digital communications means the transmission of messages encoded in binary form. The individual characters of the message are encoded into a sequence of bits (a bit is either a zero or a one). Coding systems used for teletype and other digitally-encoded messages use a string of bits to encode each of the letters of the alphabet, the numerals, and additional special characters. A six-bit string for example can be arranged in 64 (i.e., 2^6) different ways, such that the code can accommodate 28 extra characters.

The capabilities of digital communications that are important to mobile law enforcement communications are summarized below.

Speed. The same words can be transmitted in significantly less time than that required for standard voice transmission. This is very important where channels are congested, as is the case in many law enforcement agencies.

Accuracy. The receiving equipment needs to determine only whether a given pulse or tone represents a zero or a one. The signals can be quite badly distorted before this discrimination becomes difficult or impossible. From the point of view of law enforcement communications, this feature is important not only because it may avoid errors in understanding, but because it may reduce the need for repetition. It is noted however, that digital transmissions are subject to error in a near-threshold or noisy environment.

Privacy. Because digital communications are by their nature transmitted in encoded form, they cannot be intercepted by anyone without appropriate digital decoding equipment. This assures a greater degree of security for law enforcement communications, which can now be overheard by anyone with a receiver tuned to a police channel frequency (unless scrambling/unscrambling equipment is used at both ends of the link); it does not provide total security, of course, and does not prevent compromise of security if unauthorized persons gain access to the terminals.

"Canned" Messages. A digital transmitting unit normally incorporates a storage capability, which makes it possible to store a set of frequently used messages (especially status reports and acknowledgments) and cause them to be sent by pressing a single key on a console. At the receiving end, such a routine message can be decoded and displayed, in the simplest form, by turning on a light; this saves valuable time and attention for both the field officer and the dispatcher.

Direct Data Base Access. Digital messages are by their nature in a computer-compatible form. This means that a relatively modest minicomputer at a base station can automatically perform the switching required to connect the field unit to a computerized local, state, or national data base. Names and numbers associated with queries about persons or vehicles, for example, can be transmitted by the mobile unit and a reply received in as little as 5 to 10 seconds. All the necessary switching and file searching is done by computer, and the reply is automatically generated by computer. Not only is a large amount of time and manpower saved, but the possibility of error in repeating or copying numbers is greatly reduced.

Text Messages. Digital messages must be input and displayed in written form, except for the "canned" messages mentioned above. This requires more of the field officer's attention than speaking into a microphone or listening. On the other hand, a written message will remain available (stored, displayed or hard copied) until it has been read and cleared; this is an advantage when the officer is not in his car or is unable to give attention to a message at the time it arrives.

Expansion of Functional Capabilities. Addition of new capabilities, such as computer-assisted dispatch and field-report compilation, become relatively easy with the more advanced digital systems.

The planner must also be aware of possible drawbacks to mobile digital communications for law enforcement applications, since the associated equipments and techniques are still in the development stage and should not be considered a solution to all communications problems. Use of mobile digital terminals on existing RF voice links can create significant interference with voice transmissions; squelch techniques can alleviate this problem, but in many cases it is desirable to use dedicated channels for digital transmissions. Also, digital links are susceptible to significant error rates in the difficult telecommunications environments of many urban areas, requiring repeated transmission of messages and/or elaborate error detection codes, both of which detract from short transmission times. Interconnecting digital terminals with older existing RF voice transmitters can also introduce delays in digital transmissions because of relatively long warm-up times. Additional radio technicians skilled in mobile digital terminal operation may be required, with associated higher maintenance costs. And, as noted in the

Introduction, installing bulky digital terminals into already crowded patrol cars detracts from the convenience of their use and possibly officer safety.

These disadvantages are not critical, and many will be eliminated as the technology progresses, but the planner must be aware of and reflect these factors in his analysis and recommendations.

2.2 Extent of Application of Digital Communications

There are several degrees or levels to which digit communications can be applied in law enforcement work, an one of the essential steps in planning is to select an appropriat level for the agency concerned. Table 2 indicates in summar form some of the possible levels of sophistication that can b

Table 2. Levels of Application of Digital Communications

Level of Digitization	Description	Comments
Status Only		
One-way	Mobile unit can report status by pressing a single key on mobile unit console. Dispatcher's console maintains indication of last status transmission. All messages from base station are by voice.	Minimum hardware in mobile unit and minimum expense; useful in reducing channel congestion where there are many cars per channel, since status reports constitute a significant portion of traffic.
Two-way	As above, plus comparable capability for base station to transmit status or other "canned" messages (primarily acknowledgments) to mobile units by a single console key. Mobile unit displays messages as lights (no text) or numbers.	Advantages as above, plus saves significant amounts of dispatcher time used to acknowledge status messages. Lack of an acknowledgment capability by either mobile or base unit is generally not acceptable.
Full Text Plus Status	As in two-way status above, plus a full alphanumeric keyboard and display (luminous and/or printer) in mobile unit plus function keys for status and other "canned" messages.	Requires a telecommunications controller at the base station. Reduces dispatcher workload significantly and further reduces channel congestion over status-only capability.
Direct Data Base Query Capability	Mobile unit can make data base queries directly of local, state, and national data bases without relay through dispatcher.	Requires additional hardware (modems to interface with remote data base lines) and additional switching software for minicomputer. Dispatcher control and/or monitoring can be provided.
Computer-Aided Dispatching	Computer performs computations to help dispatcher locate nearest available unit or units to assign to a given incident. Verifies jurisdictional boundaries, valid address, prior complaints, and possible dangerous condition.	Can be added to any system with a computer, requiring primarily additional software. Can be provided with any level of dispatcher control. May require larger computer and more peripherals.
Automated Data Collection and Report Generation	Computer logs all messages or selected types and automatically generates reports of traffic by message type, car, time of day, or other breakdowns. Officer reports can be entered through mobile terminals, and used as part of Field Officer Daily Report although this can increase traffic significantly.	Requires additional software. Useful capability to monitor system performance and usage, trends in message traffic, etc.. May require larger computer and more peripherals.

considered. Additional discussion of the technical details and the factors that affect a selection are presented in subsequent sections.

In general, functions that are amenable to digital communications include:

(1) Status reporting.
(2) Terminal-to-terminal message transmission.*
(3) Automated data base inquiry and response.
(4) Computer-aided dispatching.
(5) Automated report generation and data collection.

Other functions amenable to digital transmission techniques include automatic vehicle location, out of car transmissions and emergency trigger.

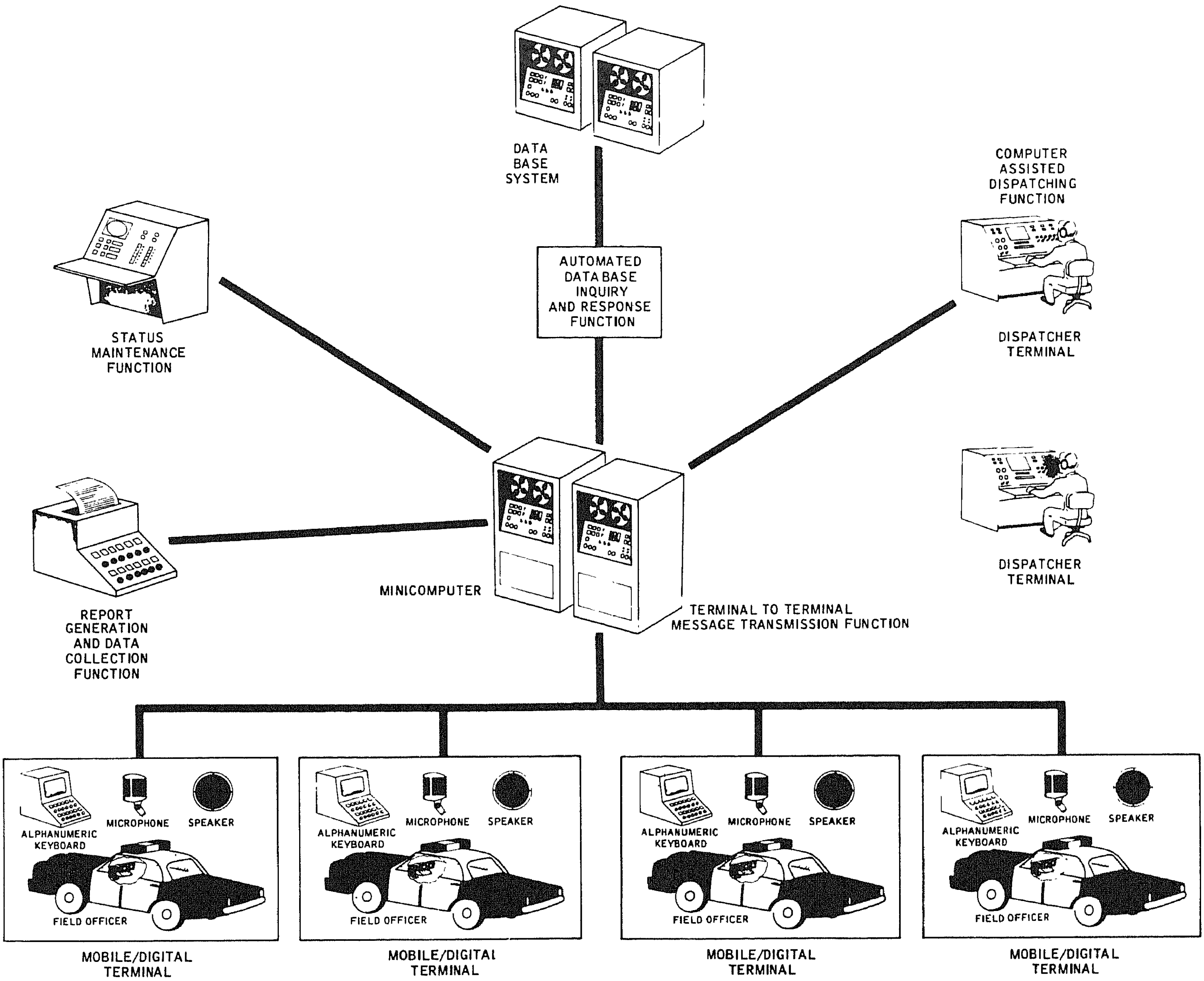
The relationships between these functions are shown in Figure 1. Depending on its individual requirements, a law enforcement command and control system may have some or all of these functions. The computer-aided dispatch and report generator functions are useful auxiliaries to the main contributions of digital communications, but generally are implemented at a later phase of command and control upgrade. A significant jump in capability is provided by the addition of a minicomputer at the base station; once this has been added it can be used for a number of new functions with relatively little additional expense, such as computer-aided dispatching and automated data base query. Primary consideration will be given to the first three functions, w... re more closely associated with digital transmissions, and usually lead to the most significant improvements in system performance, and reduced costs.

It is readily appreciated that mobile digital terminals, or digital communications in general can have a major impact on overall command and control systems, particularly if computer-aided dispatching and reporting functions are implemented concurrently with the installation of digital communications. In this sense, a digital transmission system can act as a catalyst to trigger a general upgrade in the command and control operations because of its natural interface with computer-based files, displays and message switchers. The planner should be aware of this close relationship between the changeover to digital communications and the possible need to revamp elements of the command and control system.

2.3 System Elements

Figure 2 presents major elements in a digital communication system, translating the system functions of Figure 1 to system elements required to implement the functions. The figure presents a full-text terminal-to-terminal digital system with direct data base access from the field unit. This system represents a reasonably advanced capability, although computer-aided dispatching and automated report generation functions are not included. (These elements involve added software programs and would be interfaced through the minicomputer or controller.) System elements are discussed in more detail in Chapter 5; the general types of equipments involved are indicated in Figure 2.

*Mobile to mobile transmissions would be routed first to a base station relay.

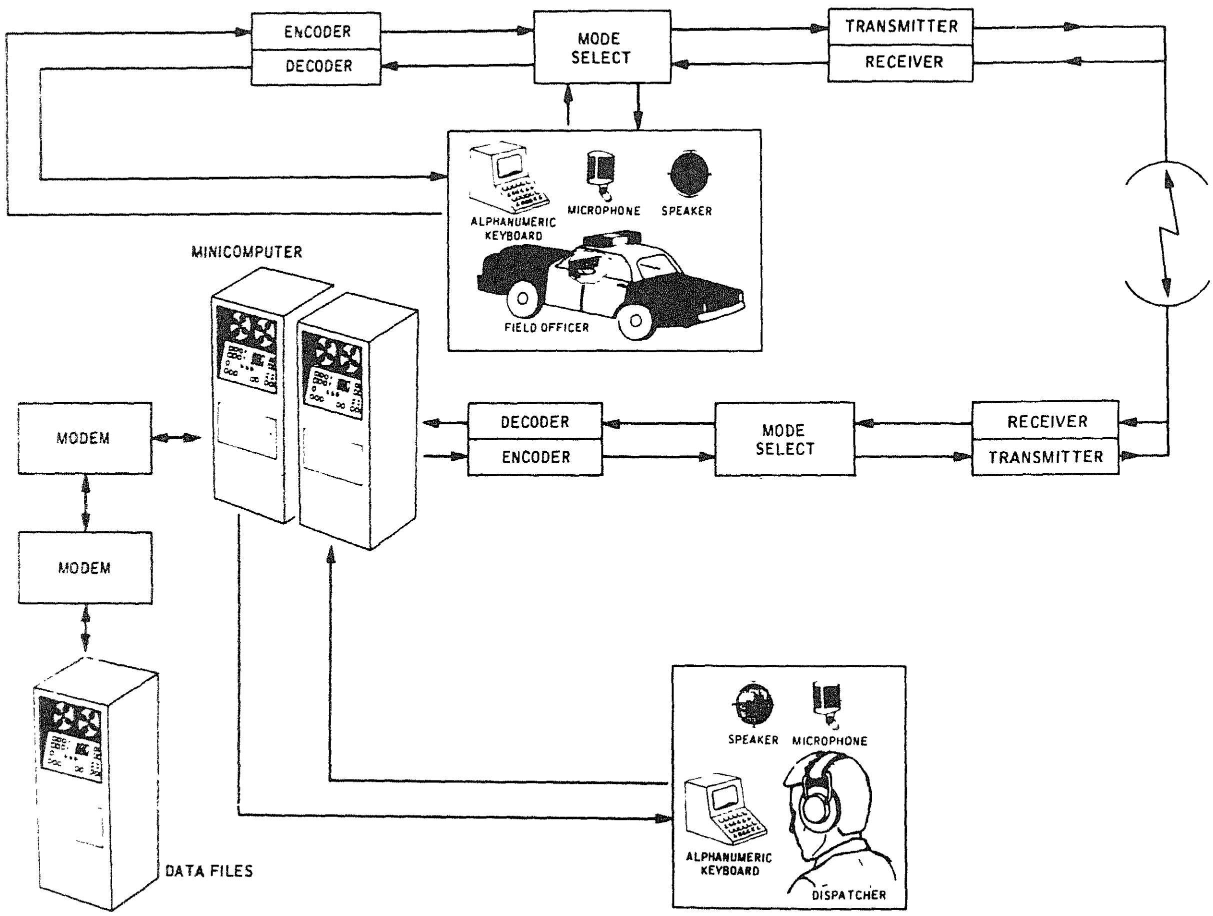


This diagram identifies the major functions that can be performed by currently available and operating mobile law enforcement communications systems. The basic function provided is terminal-to-terminal transmission of digital messages, usually between a mobile terminal and a base station. These can be either a limited set of status messages transmitted by pressing single keys or text messages composed on a full alphanumeric keyboard. The status maintenance function monitors the status of each mobile unit in the fleet; it may simply display each car to the dispatcher or store the status in a data file for retrieval by the dispatcher. Where computer-aided dispatching is provided, the minicomputer can indicate which units are available, verify jurisdiction and valid address, and retrieve prior complaint records and other information required by the dispatcher.

Automated data base query refers to direct query from mobile units; the automated query and response function already exists in many base stations. Automated message switching by the minicomputer allows any mobile unit to direct a query to one or more remote data files without going through the dispatcher and/or terminal operator. The response is also transmitted directly to the mobile unit. This traffic may be monitored and/or recorded at the base station.

Once a computer is available for other functions, it can easily be programmed to collect data on all digital message traffic and to generate any desired reports (e.g., by shift, mobile unit, area, type of message, etc.) automatically at any selected intervals.

Fig. 1. Typical mobile digital system functional diagram



The block diagram shows the principal elements of a system that provides full text capability in addition to function keys and display lights for transmitting status or other "canned" messages. The minicomputer or message switcher enables the mobile unit to make direct queries of remote data files.

Those elements that are part of an existing voice-only system are shown shaded; the unshaded boxes represent elements added to provide the digital capability. For status-only transmissions, mode select switches, encoders/decoders, logic units, and displays are required; keyboards are installed in both the mobile unit and base station. Full-text transmissions require alphanumeric keyboards and additional display capability; in addition, a minicomputer generally is used to handle message switching, control displays, log messages, and related support functions.

Automated query of data files, both local and remote, can be achieved by installing modems on the lines to the files. The minicomputer or message switcher will experience a considerably heavier traffic load in this case and may need additional memory and input/output capacity.

This diagram illustrates the variety of applications of digital communications, as well as the impact on the overall command and control system.

Fig. 2. Typical elements of a mobile digital communications system

3. PLANNING FOR DIGITAL COMMUNICATIONS

The planning process consists basically of the following four steps:

(1) Analysis of requirements

(2) Selection of system configuration

(3) Preparation of implementation plan and cost estimates

(4) Evaluation of expected benefits versus cost.

Guidelines for these four steps are given in the following chapters. Some discussion of the overall planning process may be useful as background.

A major point to be kept in mind is that the steps in the planning process are not simply done once in sequence to yield the final plan. Planning is an iterative process, where there will normally be several loops through the steps before a final plan is evolved. After the requirements have been defined and a system is being designed, it may be found that the requirements can be met only by using a more elaborate or more costly system than can be justified; in this case it may be necessary to modify the requirements. Conversely, it may be found that the system selected has more capability than needed to meet some minimum set of requirements, so that the requirements can be restated to take advantage of this capability. The planner should be prepared to go through some or all of his steps as many times as necessary to arrive at a system that is suitable for his agency and compatible with the technical, administrative, and fiscal constraints within which it must operate.

Probably the most difficult of the four steps is the first; analysis of requirements. The question to be answered is, what do we need in the way of digital communications? In almost any situation, the definition of "need" is a very flexible one. There are attitudes ranging from "if we can't afford it, we don't need it" to "if we need it, we'll have to afford it." In resolving the question of firm requirements, the planner must have the participation of the personnel who will be using the new system. They should be consulted at every step, not only because they have useful knowledge and experience to contribute but because they will accept the new system much more readily if they had a part in selecting it. Also, the planner can sometimes consider the possibility of testing digital communications on a small scale to determine what effect it actually has and how readily it is accepted. Where a large agency is concerned, this can often be done at reasonable cost in relation to the cost of implementing a complete system.

An important part of the requirements analysis, and of the whole planning process, is the determination of what trade-offs are possible and what their parameters are. A few of those that may be considered are:

- Digitization level: status only vs. full text vs. full text plus atuomatic data base query.
- More traffic vs. same volume of traffic with less crowding.
- Out-of-car digital transmission vs. mobile unit only.
- Reallocation of channels vs. existing assignments.
- Separate channels for digital transmission vs. voice plus digital channels.
- Simplex vs. half duplex vs. full duplex channels.
- Hard copy printer in mobile unit vs. illuminated display only.

Many more comparable trade-offs will come up during the analysis of any requirements and selection of a system. Some of them involve intangible factors such as officer safety and faster response to citizen calls, while others are more easily quantified: message volume versus system cost, for example.

Lastly, the planner should not assume that once his plan has been through all the steps in the planning process, it is finished. The probability is that it will need to be updated more than once before the system is implemented, as a result of changing conditions, changing requirements, changing resources, or changes in the technology of digital communications. The planner should be prepared to revise his plan to reflect these changes as they occur.

Chapter 4 provides data that will be useful in analyzing digital communications requirements for systems of various sizes and degrees of sophistication. Chapter 5 describes in general terms a number of types of hardware currently available for digital law enforcement communications and illustrates system concepts. Since both the technical characteristics and the costs of such equipment are changing fairly rapidly, the planner will ordinarily obtain the needed detailed information directly from potential vendors; a partial list of such vendors is included.

Preparation of an implementation plan is fairly straightforward once the system concept has been selected; some examples are given in Chapters 5 and 6, which also cover system cost estimating. The evaluation of expected benefits is much less straightforward, since a number of them are intangible although important. Some actual cost savings can be identified, but the dollar value of improved law enforcement and officer safety is difficult to translate into dollars. Chapter 7 discusses the factors that can enter into an evaluation, such as channel utilization, dispatch and patrol response times, service times (to clear calls), time on patrol, personnel loading and other parameters. It was found necessary in preparing this chapter to develop a computer simulation program of a police command and control system to quantify the factors listed above, from which cost benefits could be estimated. The simulation program is useful for this purpose, and is the only practical means of evaluating the overall impact of digital communications on the complete police operating system.

It should be recognized that the field of digital communications for police applications is evolving rapidly, and equipment descriptions and costs can be expected to change frequently. Many agencies are currently field testing mobile digital systems, and the results of these tests can be expected to have an impact on vendor product line developments.

4. PLANNING GUIDELINES: ANALYSIS OF REQUIREMENTS

The immediate requirement of many police agencies is to reduce congestion on existing voice links and, thereby, improve the responsiveness of the communications system. This goal can be partially achieved by adding more voice channels and more dispatchers, but the limitations and drawbacks of voice links remain; digital techniques open up basically new advantages that will influence not only communications, but command and control functions as well.

The following approach is taken to the development of requirements for a specific agency.

(1) *Functional Requirements.* Functions that can be accomplished by mobile digital terminals are outlined, so that the agency planner can select those functions for preliminary assessment. The results of surveys conducted by various police agencies are summarized to serve as guidelines.

(2) *Traffic Analysis.* In most cases it will be essential for the agency planner to conduct a brief survey of existing traffic volumes and patterns over the agency network. Techniques for conducting traffic surveys are discussed. The results of the traffic survey are analyzed to determine the fraction and type of messages that can be converted to digital transmission.

(3) *Channel Loading and Response Times.* Consideration is given to preparing estimates of network loading and response times with various levels of digital transmissions.

4.1 Functional Requirements

The first step in analyzing the requirements for a digital communications system for law enforcement is to identify those functions that the digital system will be expected to perform. It may be useful to have two sets of such functions: one that is required, plus a set that is desirable. Then, when the specifications for the system are being developed, the desired functions can be included to the extent that resources permit. In any case it will probably be necessary to review the requirements analysis after initial system definition and cost estimates have been developed.

The most direct procedure for identifying functional requirements is to make a survey among those who will be using the system, after providing them with information on what possibilities are available with digital communications. The results of two such surveys are shown in Table 3; the functions listed there can be used as the basis for a comparable survey in any law enforcement agency. Note that the list includes certain items that are features or characteristics of the system rather than functions that it performs, but it is important to determine what features are to be included because they may affect the traffic analysis as well as the overall system design, cost, and acceptance by the user personnel.

With regard to the question of combining voice and digital communications, it should not be interpreted to mean that 20 percent of the respondents preferred to eliminate voice communications. No existing or proposed system of digital communications for law enforcement operates without parallel voice communications. The response indicated that 20 percent of the respondents wanted separate channels for digital transmissions. The question of whether digital communications should be transmitted over the same channel as voice messages is a technical question discussed in Chapter 5.

Naturally the results of a survey such as those tabulated in Table 3 must be combined with the planner's more extensive knowledge of technical requirements and costs before even a preliminary list of functions can be prepared as a basis for the succeeding steps in the requirements analysis.

The survey did not address the question of automated query of information files by means of digital communications links from mobile units. This function is of extreme importance because a clear gain in response time and reliability is attainable in this area. Further, existing traffic associated with data base queries can be expected to increase significantly because of the automation factor; that is, field personnel no longer need rely on voice links and radio operators to enter requests into data file systems. Increases in this type of communication traffic are expected to reach 400 percent in the Kansas City ALERT II system. Similar growth should be allowed for by the agency planner.

4.2 Traffic Analysis

The next step in the requirements analysis is to determine the volume of traffic that the digital system should be sized to handle. This will depend partly on the level of digital service selected, and this selection in turn must be based on some evaluation of the expected benefits of adding a digital capability.

The usual procedure for a communication traffic analysis is to monitor live broadcasts or tape recordings of one or more

Table 3. Survey of Functional Requirements (Reference 1)

Item	Survey Results
1. Basic functions	• Two-way digital communication was desired (95% in favor). Only 5% were in favor of one-way printer and two-way status transmissions. • Both full text and status information was desired (85% in favor). • 50% of those surveyed were in favor of equipping all patrol units with mobile digital terminals; an additional 25% were in favor of equipping at least 75% of the patrol units. • 90% of those surveyed were in favor of automatic and/or manual acknowledgement of digital messages. • 50% were in favor of mobile to mobile digital communications. Only 25% indicated a need for base to base digital links. • 80% were in favor of combining digital with existing voice communications. (In general, there is a strong feeling that voice communications should not be deleted.) • Allocation of MDTs to a radio channel: 50 to 74 units (50%); 100 or more (15%).
2. Displays	• Stated display requirements for mobile units were reasonably consistent: 85% desired full text and status displays. The type of display was less well defined: 55% indicated a preference for visual display, and 45% for visual and hard copy. • The method of display was not well defined: 35% wanted visual displays, printer, and status lights; 25% wanted visual display plus printer, and 20% favored visual display only. • Similarly the preferred method of control center display was: 50% in favor of CRT (cathode ray tube) only, and 45% in favor of CRT and hard copy. • A high percentage of those surveyed (85% to 95%) indicated a need for special display requirements, such as: special effects for critical messages, message held until manual clear, indication of new incoming message, and the capability to store more than one received message.
3. Other operational features	• Automatic polling for status update: 55% in favor. • Dispatcher should monitor all automatic functions: 100% in favor. • Physical size and location were of concern to all respondents.

selected periods of communication traffic over existing voice channels. It is necessary to monitor during peak periods, since that is the load the system should be sized to handle. Two general types of data are derived from the observations: first, the fraction of total available time used for message transmissions, i.e., channel loading or utilization, and second, detailed message structure such as type, duration, and frequency of use. Before discussing measurement techniques, which depend on the type of data sought, we can list the following specific parameters we need to measure:

(1) The percentage of the total available "air time" during, which messages are being transmitted, or channel utilization. This is monitored on both downlinks (base to mobile) and uplinks (mobile to base). Channel loading is the single most important parameter since it gives a direct measurement of channel congestion and the effective distribution of the total traffic load between available channels.

(2) The types of messages being transmitted. Different agencies have used a different breakdown by type of message, but the following general categories are usually adopted:
   (a) Status messages
   (b) Data base queries
   (c) Text messages
       Dispatch calls
       Other alphanumeric calls

   The important point is to identify routine status and data base query messages, as well as certain text messages that can be digitized.

(3) The number of messages per hour for each type of message. It is also useful to have the number of each type per hour per patrol unit.

(4) The average duration of each type of message.

(5) The average number of words or characters in those message types that appear to be suitable for digital transmission. These values can be adjusted to account for reduced numbers of characters in digitized messages.
(6) From (3) and (4) (or by direct tabulation), the percent of the total transmission time used by each type of message.
(7) Numbers of patrol units on station during channel monitoring.

These parameters are usually measured in two steps: first, channel loading or utilization, and second, message types, volumes, and durations. A technique for measuring channel loading is shown in Figure 3a, in which a signal-operated timer is installed on the lines leading to the base station transmitter, and is activated whenever a message signal is present on the line. The timer gives channel occupancy time directly, and can be converted to channel utilization or loading factor by dividing the accumulated clock time by the total elapsed time over which the channel was monitored, typically 1 hour. This voice-operated relay technique is relatively inexpensive, reliable, and sufficiently accurate to measure channel loading.

Channel loading on uplink frequencies (mobile to base) can be measured with a similar type of clock, adjusted for the

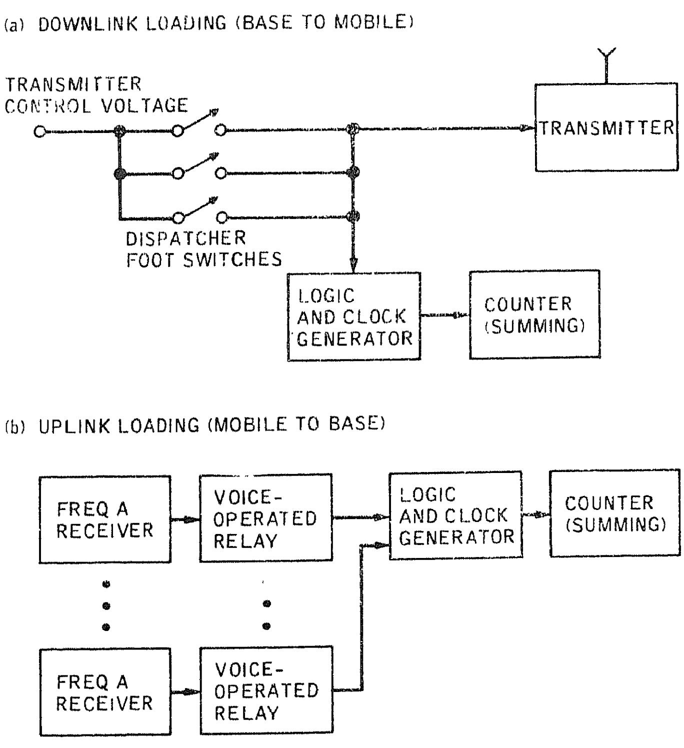


Fig. 3. Channel utilization instrumentation

lower voltages at the base station receiver (see Figure 3b). Channel selector switches are used where several frequencies are being monitored.

Measurements of message type, volume, and duration can be made from tape recordings or live broadcasts, but require that *each* message be identified as to type and duration. A stopwatch or pedal-operated timer with manual reset is often used to determine message duration but is limited in accuracy by the response time of the analyst, who also records the type of message. Tape recordings are easier to analyze because the tapes can be replayed to verify message classification and timing. Forms listing the message types of interest are prepared before start of data gathering to assist the analyst. Three or four hours of broadcasting should be monitored on both the downlink and uplink frequencies to provide an adequate sample size; peak traffic periods should be selected.

The results of such an analysis for the Boston and Fall River, Mass., police departments are summarized in Tables 4 and 5, which are based on data from Reference 1. It is difficult to compare the results of different studies because of the different breakdown used for message categories and other differences in the procedures for collecting the data; however, it is relatively easy for the planner to define categories appropriate for his agency, and conduct traffic surveys to quantify existing traffic patterns and identify those segments that are amenable to digitization. A detailed analysis is given in Section 4.4 (also see Ref. 4).

A review of the more detailed data presented in some of the studies suggests that with a full-text plus status capability, as much as 75 percent of the currently used total transmission time could be handled in digital form; a higher degree of

Table 4. Traffic Analysis for Boston and Fall River

Message Category	Percent of Total Available Time Used For Transmissions	
	Boston	Fall River
Status messages	12.9	9.1
Car identification	4.2	3.9
Acknowledgment	6.7	5.2
"Canned" message	2.0	–
"Text" messages	14.1	11.7
All messages (percent utilization)	27.0	20.8

Table 5. Message Characteristics for Boston and Fall River

Characteristic	Boston	Fall River
Percent of total available time used for transmissions (channel utilization):	27.0	20.8
Time to pass a status message and acknowledgment, sec	5.7	2.5
Time to pass a "text" message and acknowledgment, sec	10.0	35.0
Number of characters per message:		
base to mobile	60.0	61.0
mobile to base	54.0	37.0
Number of patrol units	30	20
Number of messages per 8-hr shift per patrol unit:*		
status	23	55
"text"	14	5

*The San Francisco Digicom study (Reference 3) indicates a value of 40 for status message transmissions per shift; text messages were 14 per shift.

digitization is difficult to achieve because of emergency, administrative and other messages that must be transmitted by voice only. The consequences of different degrees of conversion to digital form are discussed in the next sections.

To summarize the available data, status messages can account for about half of all messages but occupy only 25 to 50 percent of transmission time. Over 80 percent of all messages, status and text, are amenable to digital transmission, accounting for up to 75 percent of total transmission time. These rough estimates are based on the limited data available; when more agencies have accumulated operating experience with digital systems, it will probably be easier to establish some rules of thumb applicable to agencies of different size and character.

The significant factor to determine is what fraction of present voice traffic can be replaced by digital transmissions. Then, by measuring the present channel utilization factor or loading and making some assumptions about digital message transmission times, the planner can arrive at estimates for several important communications system performance parameters, in particular channel loading and message delay times as a function of the extent of conversion to digital transmissions. The following section discusses how these estimates can be made.

4.3 Channel Loading and Response Time Estimates

Basic criteria for law enforcement communications include promptness and accuracy of message transmission. Channel loading strongly affects both promptness and accuracy which deteriorate as channel congestion increases. In this section we will derive approximate values for promptness and utilization and show how these values depend upon communication link parameters that must be measured or estimated to determine the effects of adding a digital capability to a voice system. As noted earlier, it is not feasible to consider eliminating voice messages entirely, although these could be handled over a separate channel.

The procedures outlined in this section apply to analysis of a single communication channel, which normally uses one dispatcher to communicate with multiple patrol units. The results can also be extended to multi-channel systems, where a given set of patrol units is assigned a primary frequency for normal use and thus does not affect the loading of other channels.

First, let us review what the planner has learned from his traffic analysis. He has determined the following either by direct measurement or by estimating from the data:

(1) Channel loading (transmission time used as a percentage of total available "air time" on the channel).

(2) Average length of message by message type.

(3) Percent of all messages that can be digitized (derived from a review of the length and content of each message type).

(4) The average number of messages of all types transmitted per hour.

From this information we can determine the change in system performance (i.e., promptness and utilization) to be expected from various levels of digital conversion as outlined in Section 2.2. In particular, we are interested in the reduction in channel loading as a function of level of digital conversion, together with the associated reduction in message delay time and/or increase in number of messages. In most cases the added channel capacity will be used to some extent to permit additional messages, especially data base queries. If the system permits direct, automated data base queries from patrol units, the number of such queries usually rises sharply, by factors of 5 to 10, as shown in Section 1.

Before presenting general techniques for computing channel utilization based on the results of traffic surveys, a

simple example is given for the Boston police department. The improvement in channel utilization* derived from converting a single uniform message type (say, status report and acknowledgement) may be calculated from a simple formula taken from queuing theory (see Table 6 for definition of terms).

$$\rho - \rho' = \frac{NS\,(T_v - T_d)}{(3600)\,(8)}$$

That is, the reduction in channel utilization, as a fraction of time used, equals the product of the number of cars on a channel, the number of messages per car in a shift, and the difference in message time duration between a voice and a digital message exchange, divided by time conversion constants (seconds per hour and hours per shift).

This calculation is worked out for a case based on data drawn from the Boston police department, in Table 6, also based on data from Reference 1. The results show that improvement from digitization of status messages alone is not dramatic in the case of lightly loaded channels. However, if channels were heavily loaded, say 150 cars per channel, this change would be important. The effects of digitizing both status and text messages are very pronounced, as demonstrated below.

*Channel utilization is the fraction of total available time used for message transmissions.

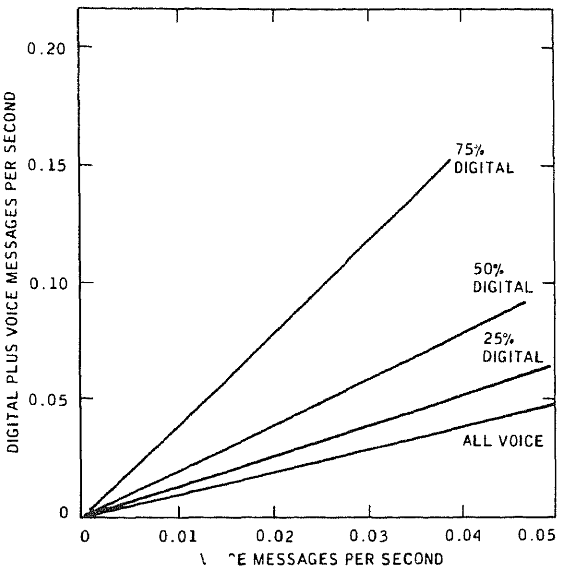
Next, we can develop a general channel utilization chart as in Figure 4a. Note that the horizontal axis is in terms of messages per second and refers to the traffic in the present, or voice-only system. The vertical axis refers to the volume of messages after the addition of a digital capability, when both types of messages are possible. Now, if we assume a given length of voice messages in the current system (as indicated in the traffic analysis of Section 4.2), we can add channel utilization plots to the basic graph of Figure 4a. The results are shown in Figure 4b for a voice transmission time of 10 seconds. The plotted lines are based on the assumption that a given digital message requires 1/10 of the time required for the same message by voice. (Other curves can be generated for other ratios of digital to voice transmission, say, 1/5*.) To take an example, on Figure 4a we could find that if the current voice-only traffic has a rate of 0.042 messages per second, then, with 25 percent digitization the new system could handle 0.056 messages per second, and with 50 percent digitization, 0.084 messages per second (33 to 100 percent increases, respectively).

The "promptness" parameter is expressed in terms of message delay time, which is the time that any given message will have to wait before being transmitted. This parameter can be plotted on the same basic graph, giving the results shown in Figure 4c.

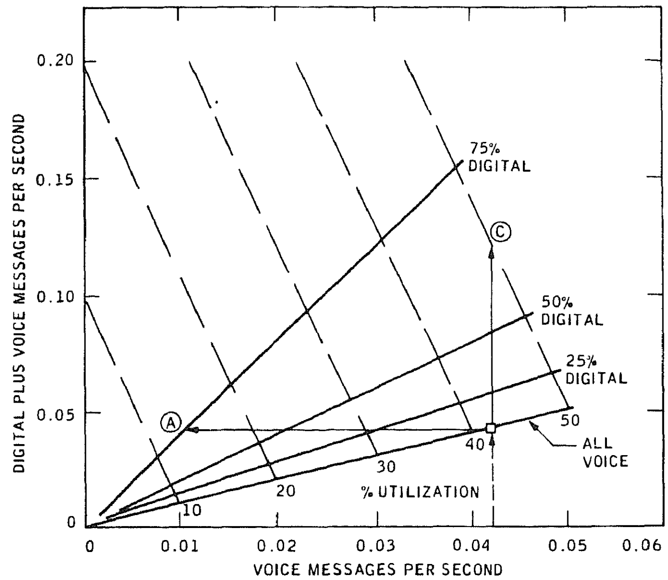
*The value of 1/10 is a reasonable upper limit for transmission time reduction based on current equipments. A more detailed analysis of a given agency indicates a reduction of about 1/8 (see Section 4.4).

Table 6. Calculation of Channel Loading Reduction by Digital Status

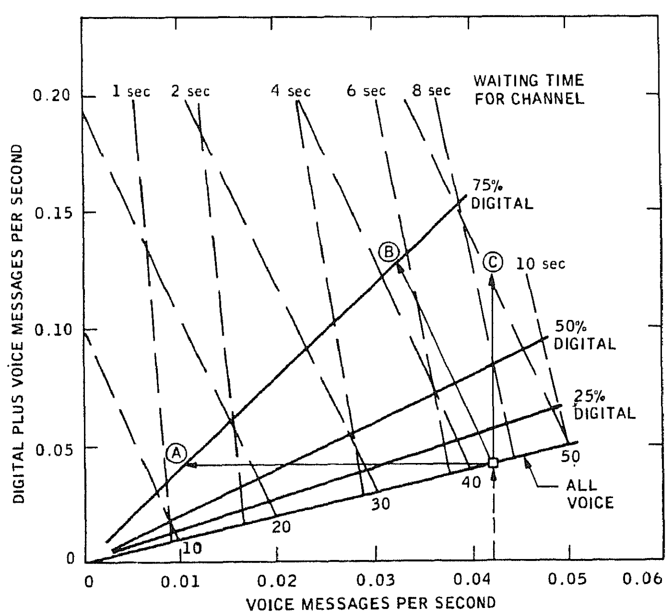
Parameter	Definition	Boston
ρ	Original channel utilization	0.27
N	Cars per channel	30
S	Status transmissions per car per shift (8 hr)	8.7
T_v	Time to pass voice status message and acknowledgement, sec	5.7
T_d	Time to pass digital status message and acknowledgement, sec	1.2
$\frac{NS \cdot (T_v - T_d)}{(3600)(8)}$	Voice-digital utilization difference = $\rho - \rho'$	0.04
ρ'	New channel utilization ($\rho - \rho'$ = change in utilization)	0.23



a. From this chart a planner can determine either the effects of varying basic communication system parameters or the effects of imposing certain constraints on those parameters. The horizontal axes represent message volume with the existing voice-only system. The vertical axes represent message volume when a digital capability has been added. The solid lines in Fig. 4a then plot the new (voice plus digital) volume as a function of percent digitization for any given old (voice only) volume. The 25 percent digitization value represents a typical status-only system; the 75 percent value is approximately the upper limit of message volume that can be digitized with the most sophisticated digital system.



b. The set of dashed lines added in Fig. 4b plots the effect of various percentages of channel loading (percent of total "air" time the channel is being used), assuming a 10-to-1 reduction in transmission time when a given message is transmitted digitally. These plots serve to indicate the degree of relief of channel crowding that can be expected for various degrees of digitization. For example, if channel loading with the old system is 42 percent, it will fall to 33 percent with 25 percent digitization and 14 percent with 75 percent digitization.



c. The dotted lines in Fig. 4c then show the effect of digitization and message volume on wait time (the average time a message must wait for the channel to be clear so it can be transmitted). This is a very important parameter for law enforcement communications, where time is often critical. The reduction in wait time to be expected from digitization can be determined from these plots: for example, if message volume remains constant a 25 percent digitization reduces the wait time from 7.2 to 4.8 sec. Conversely, if it is desired to hold wait time to some value (say, less than 5 sec), the plot shows the percent digitization that is needed to permit a given message volume. If the parameter of interest is message volume, the increase in volume permitted by various degrees of digitization can be found directly from the graph; for example, if channel loading is held constant, message volume goes up by 207 percent for 75 percent digitization.

Fig. 4. Channel loading parameter analysis

With the basic information given in Figures 4b and 4c, the planner can quickly estimate the effect of various levels of digitization on system performance. Usually he will have to deal with two limiting constraints: (1) the amount that the traffic can be digitized; and (2) the extent to which channel loading can be tolerated. For example, if the original channel loading was 42 percent and the total number of messages (voice plus digital in the new system) is to remain constant, let us examine the effect of digitizing 75 percent of the traffic. (This is the approximate upper limit indicated by the traffic survey data.) Moving horizontally on Figure 4b from the original operating point (indicated by the square) to the 75 percent digitization line, the corresponding channel utilization is found to be 14 percent, or a third of the original value.

If the limit on digitization were 25 percent, corresponding to a status-only system, following the same horizontal line (constant message volume) would show channel loading reduced to 33 percent from the original 42.

The most important performance parameter is delay time, which is found from Figure 4c. Following the same horizontal line and interpolating between the waiting-time curves, we find that for 75 percent digitization, the delay time is 1.3 seconds, and for 25 percent digitization, it is 4.8 seconds (compared to the original 7.2 seconds). This provides a very fast and simple estimate of the performance improvement in this parameter that can be expected from the two levels of digitization. It should be noted that these are average waiting times; some waiting times will be shorter, and some much longer.

The reduction in channel loading provided by digitization can also be used to increase the total number of messages, keeping the channel loading constant rather than the number of messages. The result (point B on Figure 4c) for 75 percent digitization is a 207 percent increase in messages per second and a delay time reduction to 5.7 seconds.

Another possibility is to keep the number of voice messages constant and add digital messages until an upper limit on channel loading is reached. Using 50 percent as this upper limit, we find point C on Figure 4c; this indicates that the number of messages has increased by 188 percent, but delay time has also increased to 8.5 seconds.

This illustrative example is given to show how the various communication system performance parameters can be varied or held constant to determine the effects of various levels of digital conversion, or conversely the amount of digitization needed to achieve certain performance parameters. The input data can of course be varied to reflect the assumptions for the given system and degree of digitization.

4.4 Detailed Channel Loading Analysis

Because of the importance of measuring channel loading and developing realistic estimates of potential reductions through the use of digital communications, a detailed analysis is presented for a set of data given in Reference 5 for the Los Angeles Police Department. A scheme for categorizing message types and message durations associated with these types is given, and provides an excellent basis for estimating channel loadings with various digitization levels. Much data was gathered during the course of the monitoring project and yielded the following:

(1) Types of messages sent from base stations and mobiles.

(2) Message counts.

(3) Durations for each type of message.

(4) Channel loading.

(5) Number of vehicles using each frequency.

The types of messages were determined by listening to live broadcasts. Detailed lists of message types were constructed and aggregated into four general categories. This list is shown in Table 7 for the downlink (base to mobile); a similar list was developed for mobile to base traffic. Data base "yes" replies (1) are relatively long messages but are usually given in a standard format that can be easily digitized. Status messages (2), which comprise the bulk of message transmissions, are of short duration, and can be easily digitized and transmitted by depressing a single key. The calls for service and dispatching messages (3) require the input of alphanumeric data through a full text keyboard and can be handled relatively easily by the dispatcher or RTO; preselected formats would be displayed on a CRT screen to minimize typing. The last category of messages, additional alphanumeric calls (4), is handled much the same as type (3) traffic. The planner may wish to handle these messages by voice since they occur less frequently and also require preselected screen formatting. Separate but generally similar categories were devised for uplink traffic. Individual agencies will want to develop classifications to suit their particular needs, but the four basic classes of messages are convenient for developing a useful data base.

Uplink and downlink frequencies were monitored for periods of 1 hour each to establish message durations and volumes. Data are available for each type of message listed in Table 7, but it is usually adequate to aggregate the totals by category for purposes of channel loading analysis. The results for a downlink monitored during a 1-hour peak period (21:50 to 22:50 on Friday) are:

Category	Number of messages	Percent of messages,	Message duration, sec	Air time, sec	Percent of air time
1. Query response	57	9.0	5.31	303	14.2
2. Status	385	60.6	1.71	658	30.9
3. Calls for service and dispatching	84	13.2	6.74	566	26.6
4. Other alphanumeric	109	17.2	5.51	601	28.3
	635	100.0		2128	100.0

Channel loading is obtained by dividing the air time, 2128 seconds, by the total time available, 3600 seconds, or 59.2 percent. This indeed is a heavily loaded channel and expected waiting times are relatively high - 5 seconds or more. Status messages comprise the bulk of transmissions - 60.6 percent - but use less than one-third of the air time - 30.9 percent. Categories 1 - 3 together use 71.7 percent of the air time, which is a reasonable upper bound on the degree of digitization that might be employed. Approximately 40 patrol units were deployed during the monitoring period, and, on the average, 16 messages were sent to each unit during the peak hour. Similar data for the uplink (mobile to base) show a channel utilization of 42 percent, which is also excessive for design purposes. Status messages comprised 47 percent of all transmissions and used 18.5 percent of the air time. A total of 370 uplink messages were sent, or slightly more than 9 per unit per hour. Detailed message distributions for the uplink and downlink transmissions are shown in Figure 5.

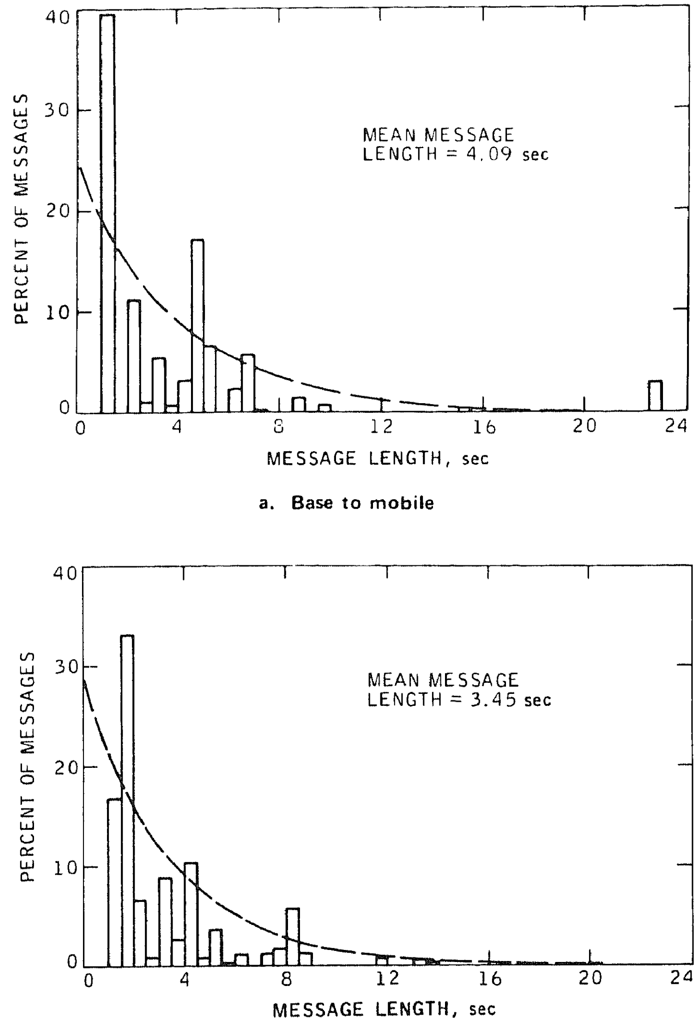
We now have sufficient data on the all-voice channel to develop comparisons with shared voice-digital channels and all-digital links. In all cases, a voice link must be available for emergencies and as backup to the digital links; dedicated digital links can be considered if a channel can be made available for this purpose; otherwise, a shared link must be used. We will compare these three modes using the message parameters developed previously. First, we must establish message lengths for digital transmissions in terms of characters per message, and convert to message duration by dividing by the digital transmission rate in characters per second. Transmission rates vary considerably from one equipment manufacturer to another, depending upon modulation techniques, the number of detection and correction bits, overhead bits, and degree of redundancy. A rate of 50 characters per second represents a lower bound, and 700 per second an upper limit; an average value is 150 characters per second, and is used in the following calculations. Message lengths were selected on the basis of past studies and are representative of current design values. For a shared voice/digital downlink:

Category		Characters per message	Message duration, sec	Messages per hour	Air time, sec
1. Query response	No hit	25	0.168	242	222
	Hit	100	0.671	43	61
2. Status		8	0.054	385	309
3. Calls for service		150	1.007	84	148
4. Other alphanumeric calls (by voice)			5.513	109	683
				863	1423

Channel utilization = 0.396
System delay = 0.750 sec

Table 7. Classification of Message Types (Base to Mobile)

Category	Type
1. Data base replies	No want/warrant
	Yes want/warrant
	No want/warrant (DMV)
	DMV information
2. Status	Roger
	Standby
	Repeat
	Clear (unit is available)
	Code 1 (come in)
	Go ahead
	ETA
	To station
	Did you receive call?
	Call watch commander
	Frequency clear
	Location
	Status
	Disregard
	Go ahead with second (suspects)
3. Calls for service and status dispatching	Code 7 (out to eat)
	Code 4
	459 now (burglary in progress)
	459 report
	211 (robbery)
	211 silent (silent alarm)
	415 disturbing the peace (by following)
	Shots fired (at)
	Ambulance shooting (unit on way)
	Ambulance traffic (unit on way)
	GTA
	GTA progress
	ADW progress
	Code 3 (lights and siren)
	Code 6 (out for investigation)
	486 (theft call)
	586 (illegally parked vehicle)
	Car racing
	Prowler (at)
	Traffic accident (at)
	Miscellaneous
4. Additional alphanumeric calls	Cancel
	Verify
	Meet at location (address)
	Meet on Tac frequency 2
	Suspect data
	Address
	Handling
	Backup (the following unit)
	Assigned stolen (for stolen vehicle)
	Miscellaneous



a. Base to mobile

b. Mobile to base

Fig. 5. Message distributions

All messages have been digitized except category (4) transmissions, which are sent by voice as before. The number of query responses (category 1) has been increased by a factor of five compared to the all-voice value to account for the typical jump in queries made by patrol units equipped with automated MDT query capability (see Section 1). A system delay time is added to all messages to account for transmitter and receiver rise times, relay actuations, and other functions not included in the message service time proper; delay times vary considerably from system to system, depending on the design, age, and condition of the equipment. New, all-digital systems will have much shorter delay times, in some cases less than 0.1 second. Since the average duration of the digital messages in the above example is 0.475 second, the importance of reducing delay time is evident if we are to take full advantage of the inherent high speeds of digital communications. Other examples with shorter delay times are presented

below. In the above example, the channel utilization is 39.6 percent, which is 45 percent reduction in an equivalent all-voice channel with the same system delay time.

With these basic parameters, we can now compute the effect of patrol fleet size on channel utilization, and estimate the waiting times for messages to acquire a clear channel. The first computation is straightforward since channel utilization varies directly with the number of patrol units in the fleet. The increase in channel loading with increase in fleet size is shown in Figure 6a for the shared voice/digital channel with various degrees of digitization. The all-voice system is heavily loaded with the present number of patrol units and cannot handle additional units without extreme congestion; digitization of category (1) - (3) messages gives considerable relief, but no more than 50 to 60 units can be served by the shared channel with a 750-millisecond system delay time. The effect of reducing delay time to 100 milliseconds is shown in Figure 6b; 70 to 80 units at most could be served by this channel.

All digital links with short system delay times can handle fleets of up to 200 patrol units, as shown in Figure 6c; a separate voice link must be provided to handle category (4) messages, emergency dispatching, and other transmissions not suitable for digitization.

Typical uplink (mobile to base) performance is shown in Figure 7 for the 40-unit fleet discussed above. The uplink is less heavily loaded, but should be reduced for good response time. About 370 messages per peak hour are transmitted on the uplink, or about 9 messages per unit per hour.

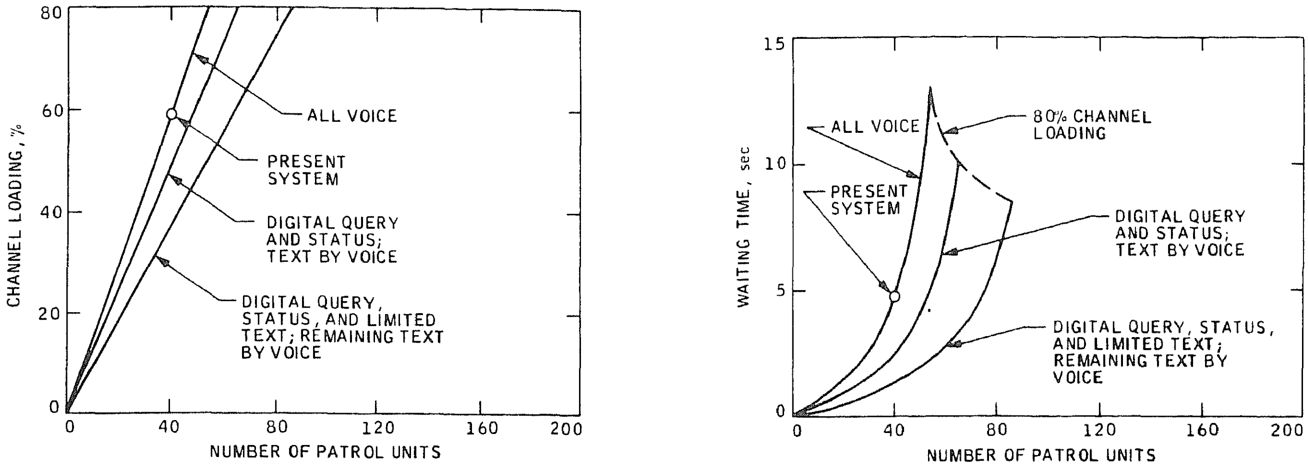
Waiting time, i.e., the delay in receiving an open channel, is an important system performance parameter and gives a direct indication of channel congestion. Queueing theory can be used to estimate waiting times if actual message length distributions (Figure 5) can be approximated by reasonably simple analytical functions. Somewhat better approximations can be obtained from computer simulations, and were used to compute the results shown in Figure 6. The simulation programs are shown in flow diagram form in Figure 8. In general, waiting times reach very large values as the channel approaches saturation, and channels should not be designed for peak loadings in excess of 30 to 40 percent.

In summary, congested voice channels can be improved by partial digitization, but the improvements are limited if system delay times are high (i.e., 500 to 1000 milliseconds). A fleet size of 100 units is a reasonable upper limit for shared voice/digital channels; fleet sizes of 200 units can be accommodated by all digital links, but a separate voice channel must be provided to supplement the digital link. Recent trends in system design favor the latter approach. The individual planner may reach different conclusions for less heavily loaded networks; a key factor to examine in this regard is the number of messages per patrol unit per hour. In the example cited, each unit receives or transmits a total of 25 messages per hour, which is relatively high compared to observations made of other agencies.

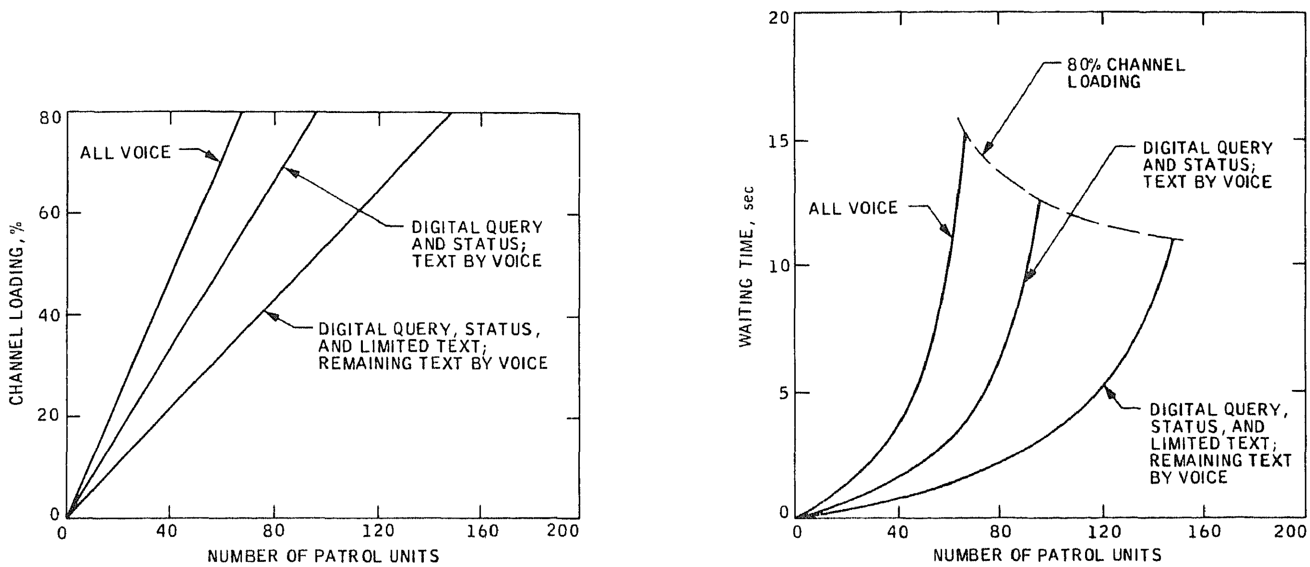
A few comments are in order about downlink versus uplink loading. Typically, downlink (base-to-mobile) loading is considerably heavier than uplink (mobile-to-base) loading because the dispatcher initiates most exchanges related to calls for service, and arranges for cover cars, relays additional information as it becomes available, and generally monitors and supports field activities. Experience with operational computer-aided dispatch systems has demonstrated the practicality of replacing conventional manual systems with CRT/keyboard terminals *if* the CRT terminals are carefully designed and checked out to give the dispatcher maximum support through use of preset formats and single-function keys for entering and transmitting routine "canned" messages; in essence, providing a "natural" system for handling incidents and managing field forces. It is not unreasonable for the dispatcher to type in a significant amount of data through the keyboard, which opens the possibility of reduced channel loading through use of digitized communications. These advantages apply for many types of mobile digital terminals: those with hardcopy printers, as well as terminals with full-text displays.

The planner *cannot* place the same heavy keyboard typing load on the field officer for obvious reasons, and since uplink (mobile-to-base) loading is not severe, there is a lesser need to reduce channel loading by digitizing a large percentage of uplink transmissions. Most users agree that *status* messages are easily handled by digitization since single keys can be used for this purpose (and more easily than voice). Five to eight keys are adequate to cover most types of status messages.

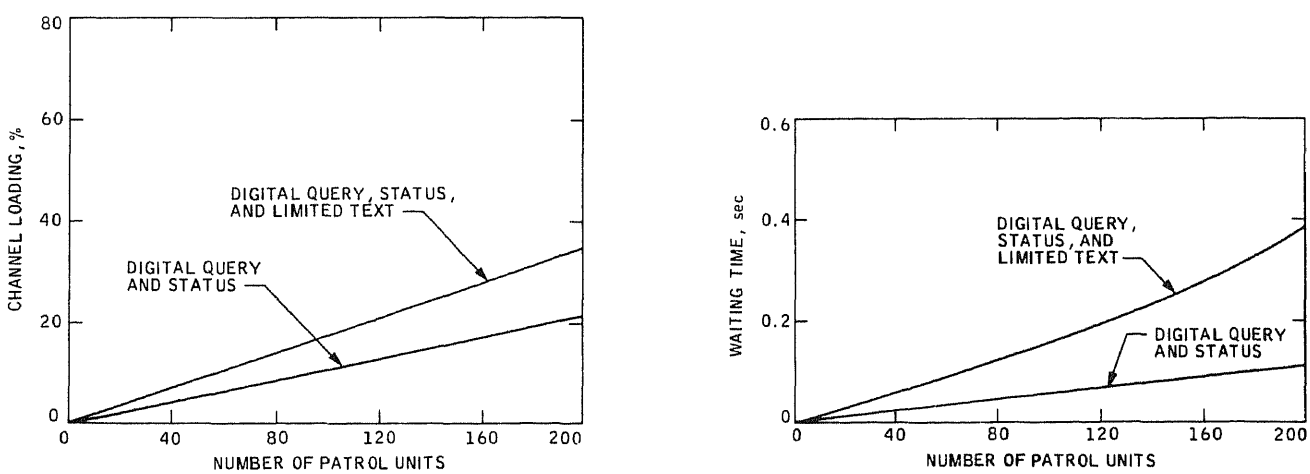
Data base queries from the field require a full text (alphanumeric) keyboard, although license tag and persons checks typically can be made with 8 to 20 characters. Such transactions do not impose excess typing loads on the officer, and digitizing them can save considerable time if the query is automatically switched to the data bank without voice relay through an operator. Agencies using mobile digital terminals for this purpose report good officer acceptance and no adverse effects on officer work load. The planner must consider the agency's policy regarding data base queries, i.e., whether frequent use of information files is encouraged or restricted. Heavy use of data banks makes it more attractive to digitize this function.



a. **Shared digital and voice traffic (transmission delay time = 750 milliseconds)**



b. **Shared digital and voice traffic (transmission delay time = 100 milliseconds)**



c. **Dedicated digital link (transmission delay time = 100 milliseconds)**

Fig. 6. Channel loading and waiting time with shared digital and voice traffic and dedicated digital links (base to mobile)

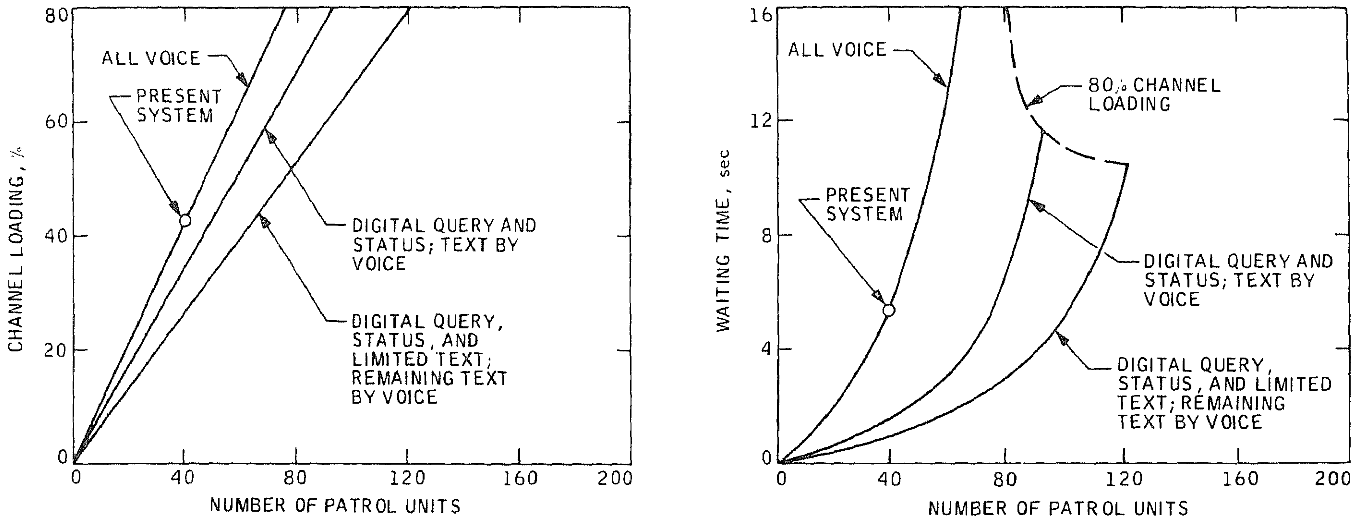
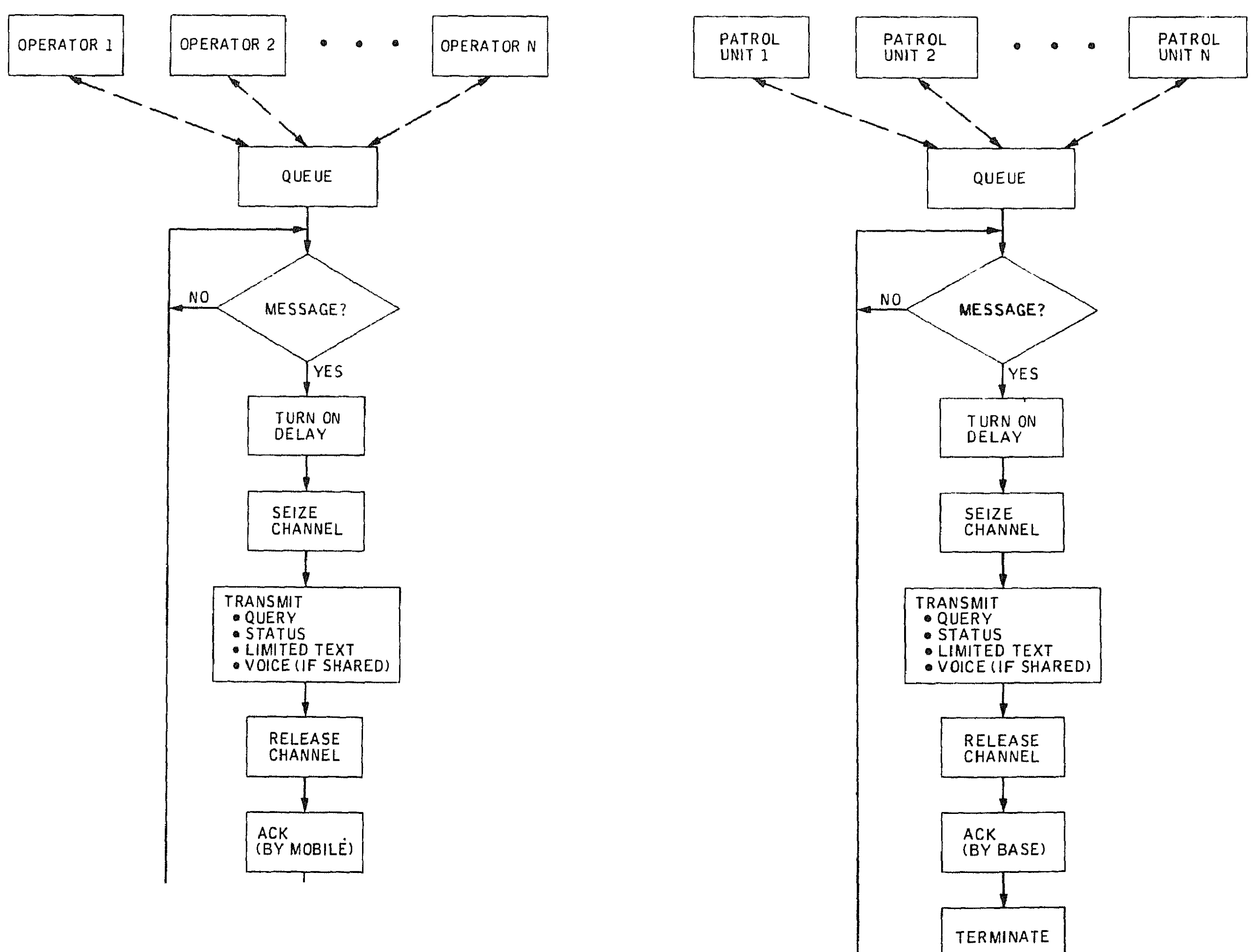


Fig. 7. Channel loading and waiting time with shared digital and voice traffic (mobile to base; transmission delay time = 750 milliseconds)



b. Mobile to base

Fig. 8. Link simulation

Field report messages through mobile digital terminals does not appear feasible or warranted, and would detract from the officer's primary role. *If* the dispatcher's work load permits, and *if* the voice channel is lightly loaded, some incident report information can be given to the dispatcher by voice for entry into computerized data files. The individual agency planner must make this determination after appropriate discussions with dispatch and field personnel, and careful analysis of the agency's work load.

Finally, the degree of digitization of mobile-to-base transmissions will be influenced by the use of one-officer versus two-officer patrol units. Two-officer units are better able to handle full-text transmissions, but the larger size of these terminals congest an already crowded patrol car, and may prevent easy access to weapons and restrict movements of the officers in emergency situations. More operational experience must be acquired to resolve these issues, but improvements in display size and visibility, and keyboard size and accessibility should be major goals of product improvement programs.

Use of MDTs during emergency operations is of course restricted, for example, when speed is necessary in answering an urgent call or when visual observation by the officer is required. The agency should give serious consideration to the classification of messages of a routine or emergency nature, and establish appropriate regulatory measures. Consideration must also be given to the policy of making dispatch assignments directly through the officer's MDT, such that other units in the area would not be aware of the assignment. The dispatcher might wish to transmit copies of the dispatch to certain other units for information purposes, but broadcasting dispatches to all units is not desirable because the officer cannot divert his attention to read all dispatches.

Results of a field test program of several terminals are given in Appendix E, pointing out transmission accuracies achieved, and several desirable as well as undesirable operating features of the equipments. A similar test program can be of great value to the planner in establishing the feasibility of MDTs for his agency (with a fairly modest investment in time and funds).

5. PLANNING GUIDELINES: SELECTION OF SYSTEM DESIGN

The planner evaluating the potential addition of a digital capability to his law enforcement communications system has to determine not only the performance characteristics of different configurations, but the basic design of each system he considers for possible implementation. This involves consideration of a number of trade-offs of technical features so that a consistent and optimum set of technical characteristics can be selected. This section identifies some of these trade-offs and briefly outlines the considerations that must be weighted for each.

5.1 Level of Digitization

The basic characteristics of the different levels of digitization of message traffic were outlined in Sections 4.2 and 4.3. Figure 9 shows block diagrams of the basic system types to be considered and identifies the hardware required in each case. Definitions of the special hardware items for handling digital messages are given in Table 8.

The selection of a given level will depend not only on the funds available for adding a digital capability, but on how badly such a capability is needed (for example, is channel congestion a serious problem?). The major factor in most cases will be channel loading and the associated delay times. If only a relatively moderate degree of relief is required, the status-only system may be all that is required, and even a one-way status-only system might be sufficient. The difficulty with adding only enough capability to solve the current problem is that the relief may not last long enough to justify the expense; in a short while channels may be overloaded again, requiring a new analysis, design, and procurement effort.

The tradeoffs to be considered in choosing a level of digitization are best illustrated by referring to the example developed in Section 4.4 for a relatively congested channel that has reached saturation and must be relieved by partial digitization, or by the addition of an extra channel. Several alternatives are given, and a possible solution is indicated.

For the case selected, the current all-voice channel loading is 72 percent. This value includes message service time and system delay time, which is estimated to be 750 milliseconds per message for equipment rise time, relay actuations, and other system response time factors. (The actual delay time was not measured, but the assumed value is representative.) Channel loading to this level is highly undesirable because of unacceptable waiting times to obtain a clear channel for message transmission; on the average, a user must wait 9 seconds for a clear channel, and often considerably longer. We have several choices: digitize some or nearly all messages and transmit them over the existing voice channel, or transmit the digitized messages over a dedicated digital channel. A third choice is to add an additional voice link. The various options are listed in Table 9 with the estimated waiting times.

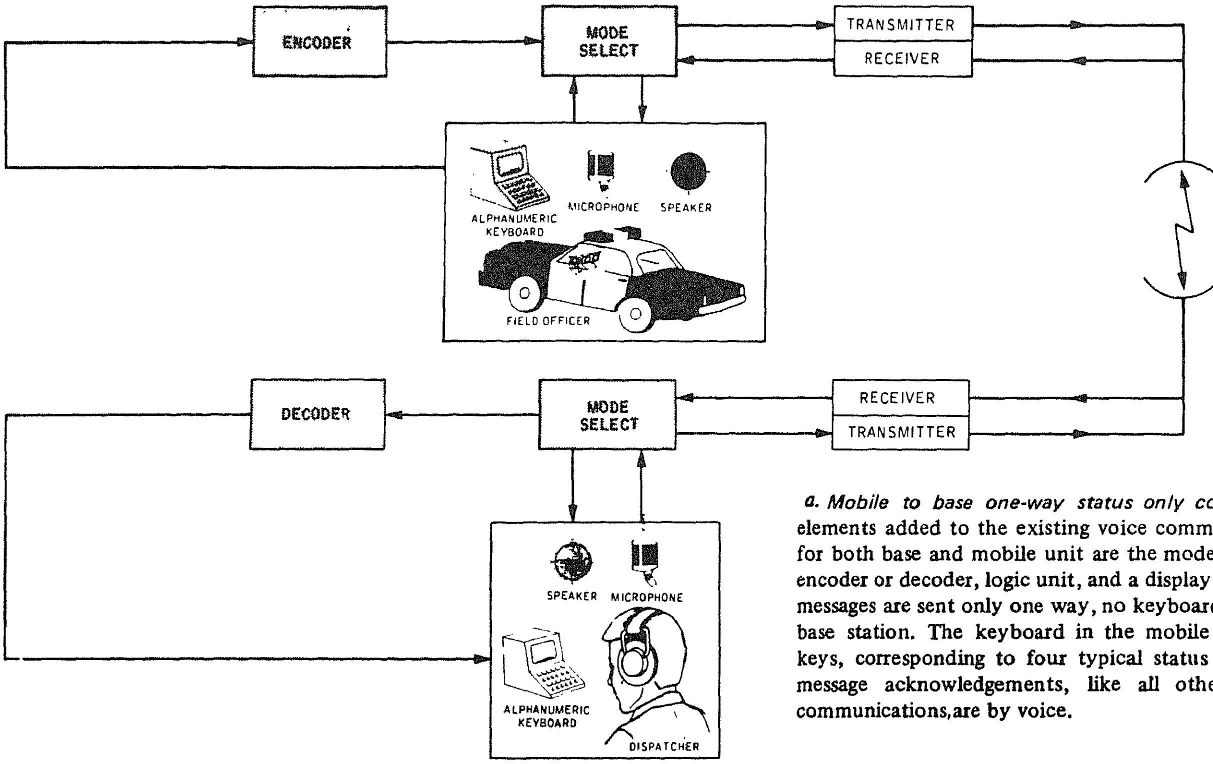
The shared voice/digital channel does not significantly reduce channel congestion or waiting time if digitization is limited to data base queries and status messages, even though the latter comprise nearly half of all messages. If limited text (calls for service dispatches) is also digitized, channel loading is reduced to 40 percent, which is still excessive from a design standpoint. For example, an unusually busy period would create unacceptable waiting times, so that the basic problem is unsolved, and fleet size could not be increased since this, too, would create congestion, This is a rather surprising result, and is due primarily to the large system delay time of 750 milliseconds incurred by every message transmitted. System delay time *by itself* accounts for a channel load of 18 percent for case (2).

Unless the system delay time can be reduced to a few hundred milliseconds, the planner must consider a dedicated digital channel in addition to the original voice channel (case 3). By digitizing queries, status messages, and limited text, voice channel loading is reduced to 19 percent, which is acceptable; loading on the digital channel is minimal because a much lower system delay time is attainable with new digital equipment. A possible drawback is the added typing load on the dispatcher; however, call-for-service dispatch messages are amenable to digitization and are currently handled in this manner in the several computer-aided-dispatch (CAD) installations now in operation (see Section 1.2).

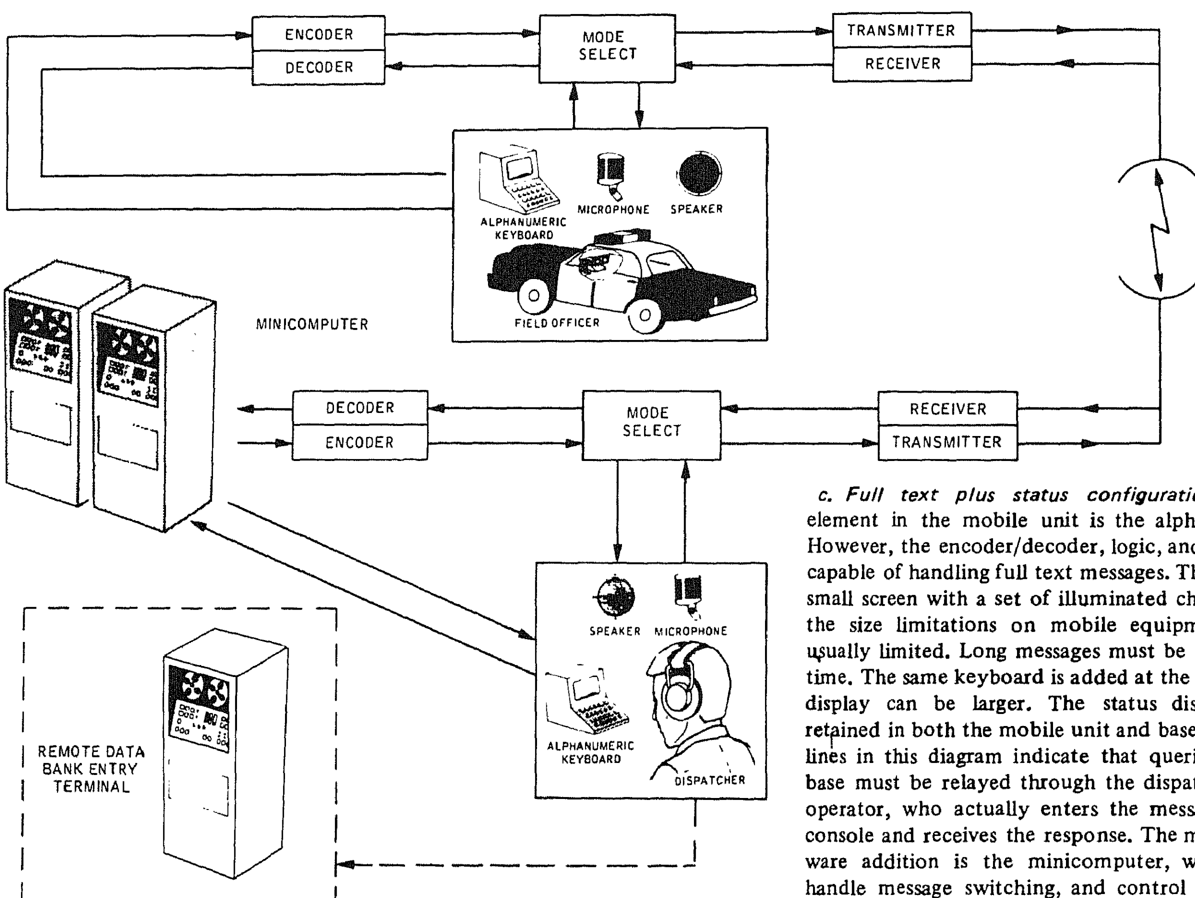
Case (4), which requires the addition of a voice channel, does not reduce channel loading sufficiently if system delay time is not reduced.

We should mention the possibility of increasing the speed of digital transmissions. (A value of 150 characters per second was used in the example.) Transmission rates of 700 characters per second are being developed, and would improve case (2) to some extent; unfortunately, the results are still dominated by system delay times, which must be improved before faster digital transmissions can be fully exploited.

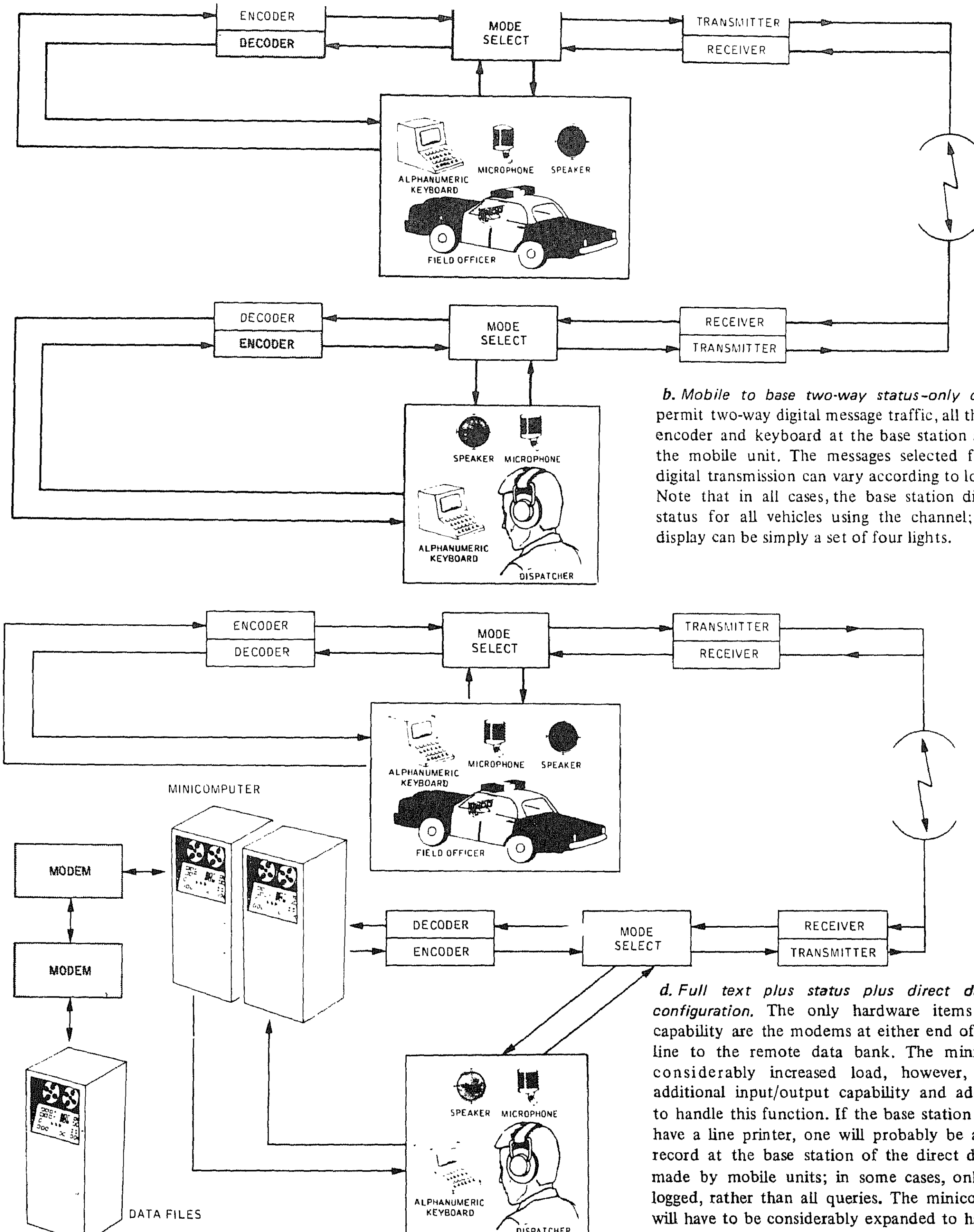
It is important to note that the original voice channel is so congested that messages are "compressed" by the dispatcher during busy periods; this effect has been noted on similar networks and leads to an understatement of demand,such that an



a. Mobile to base one-way status only configuration. The elements added to the existing voice communication system for both base and mobile unit are the mode select switch, an encoder or decoder, logic unit, and a display. Since the digital messages are sent only one way, no keyboard is needed at the base station. The keyboard in the mobile unit shows four keys, corresponding to four typical status messages. Status message acknowledgements, like all other base to mobile communications,are by voice.



c. Full text plus status configuration. The only new element in the mobile unit is the alphanumeric keyboard. However, the encoder/decoder, logic, and display are all fully capable of handling full text messages. The display could be a small screen with a set of illuminated characters. Because of the size limitations on mobile equipment, line length is usually limited. Long messages must be composed a line at a time. The same keyboard is added at the base station, but the display can be larger. The status display indicators are retained in both the mobile unit and base station. The dashed lines in this diagram indicate that queries to a remote data base must be relayed through the dispatcher and a terminal operator, who actually enters the message on the terminal console and receives the response. The most significant hardware addition is the minicomputer, which is required to handle message switching, and control displays. Depending on the capability of the computer, additional functions, such as message logging, traffic data collection, and report generation can be included.



b. Mobile to base two-way status-only configuration. To permit two-way digital message traffic, all that is needed is an encoder and keyboard at the base station and a decoder on the mobile unit. The messages selected for base-to-mobile digital transmission can vary according to local requirements. Note that in all cases, the base station display must show status for all vehicles using the channel; the mobile unit display can be simply a set of four lights.

d. Full text plus status plus direct data bank query configuration. The only hardware items added for this capability are the modems at either end of the transmission line to the remote data bank. The minicomputer has a considerably increased load, however, and may need additional input/output capability and additional memory to handle this function. If the base station does not already have a line printer, one will probably be added to make a record at the base station of the direct data bank queries made by mobile units; in some cases, only the "hits" are logged, rather than all queries. The minicomputer software will have to be considerably expanded to handle the remote data bank queries. Note that the terminal and operator at the base station are no longer required to relay queries from mobile units (although the base station will certainly have the same capability, it is no longer a part of the mobile communications system).

Fig. 9. System configurations for four levels of digitization (The elements that make up an existing voice-only system are shown in open blocks. In the successive levels of digitization, the elements that are added to the previous configuration are tinted gray.)

Table 8. Definitions of Digital Hardware Equipments

Item	Description and Function
Keyboard	For a status-only system, the keyboard on the MDT (Mobile Digital Terminal) mounted in each patrol unit has only a few keys, one for each status to be reported (four in a typical case). In a two-way status-only system, the base station will have the same equipment.
Alphanumeric keyboard	For a full text capability, a keyboard with all the letters of the alphabet and the numbers 0 to 9, plus required space, punctuation, and special keys, is mounted on the MDT. Usually, the status keys are also retained so that the field officer need not actually compose a message on the keyboard to report status. Additional function keys are generally present, at least for such required operations as CLEAR (to clear an incoming message from the display) and TRANSMIT (to send a message that has been composed on the keyboard and displayed for the field officer or dispatcher to check before transmission). The base station will have an identical keyboard.
Display	The display on the MDT is usually a set of LEDs (Light Emitting Diodes) or similar devices for displaying alphanumeric characters (similar to the displays on pocket electronic calculators). The display may be a CRT (cathode ray tube, as in a TV set), although CRTs offer some problems for use in mobile terminals and are currently used in base stations only. In a status-only system, the display may be simply a set of lights that indicate what status is currently signaled plus a light to indicate acknowledgement. At the base station, status is displayed for all the cars on the channel, and the display is necessarily more complex.
Logic unit	This term designates the electronic circuitry that takes the signals from the keyboard and outputs them to the encoder and conversely interprets the signals from the decoder to select the lights or alphanumeric symbols to be illuminated and turn them on. In some cases, the logic unit is a minicomputer with relatively sophisticated capabilities.
Encoder	This equipment takes the signals from the logic circuitry and changes them into sequences of zeros and ones. It also automatically adds the "overhead" bits for each message (preamble if used, parity bits, etc.)
Decoder	This equipment performs the reverse operation, taking the received sequences of zeros and ones and converting them into signals that cause the logic circuitry to generate the correct display characters (or turn on the correct display lights).
Mode select	This electronic circuitry determines whether the message being transmitted or received is digital or voice, and switches it accordingly to the encoder/decoder or the speaker/microphone. Priority is always given to voice transmissions.
Remote entry data bank terminal	In the diagram of the full text digital system, this refers to the console at the base station from which queries are directed to the local, state, or national data bases. A special operator (or sometimes the dispatcher himself) relays the queries received from the mobile units (either in digital text or by voice) by entering them manually on the console keyboard. Responses appear on the console display and are relayed, in digital text form or by voice, to the mobile unit. In Figure 9d, this function is handled by the minicomputer.
Modem	This equipment (a MODulator/DEModulator) is used to interface digital equipment with transmission lines carrying signals from one location to another. A modem is required at each end of the transmission line.

upgrade in channel capacity does not reduce loading by the expected amount. Also, a digital capability tends to generate its own traffic, as demonstrated in Section 1.2; agencies that have installed digital links experienced a 500 percent increase in data base queries because of the ease, speed, and convenience of transmitting messages. Both of these effects make it essential for the planner to provide for substantial growth when considering upgrades.

The above example is for a downlink (base to mobile), which is generally more heavily loaded than the uplink. We can expect uplink congestion to be reduced to an acceptable level if downlink congestion is cured, although the planner must not impose an undue typing load on the field unit by digitizing many of the text messages. Uplink digitization should be restricted to status and query messages, with little if any text digitization.

As will be indicated in the cost/benefits analysis of Section 7, an important consideration in selecting a level of digitization is the reduction of workload on the dispatcher(s). In medium or large systems, digitization may significantly reduce the dispatch workload. Direct data base query capability also reduces the work load on the remote data bank terminal oper-

ator, and may permit the reallocation of personnel in this category.

5.2 Dedicated Digital Channel vs Shared Voice Channel

The planner must consider whether the digital system is to be combined with primary police voice communications channels or if the system should have a separate channel, with voice capability, dedicated primarily to digital transmissions. Aside from channel loading considerations discussed in Section 5.1, characteristics of current voice equipments (discussed in Section 5.5) could result in less than optimum conditions for digital transmissions. In addition, the introduction of digital tones into a previously voice-communications channel can be disconcerting and even disruptive to the users. With the probable growth due to the greater number of digital message transmissions, population increases and other factors, it appears prudent that the planner give careful consideration to a dedicated digital channel.

In many cases, however, there may not be enough total channels available in a small or medium size system to permit allocating one for digital transmission only. And in large systems where the different channels are allocated to different geographic areas, the antenna coverage problem may not allow the entire area to be reached by a single digital channel. It is not practical to duplicate each voice channel with a digital channel covering the same area.

5.3 Simplex vs Half Duplex vs Full Duplex Channels

Existing mobile communications channels are operated in one of the following modes (see Figure 10):

- *Simplex.* All transmissions, mobile to base and base to mobile, use the same frequency. Therefore, if any patrol unit or the base station is transmitting, no one else can transmit a message or receive any other message.

- *Half Duplex.* The channel is divided into two frequencies. The base station transmits on one frequency and receives on the other, so that it can transmit and receive simultaneously. The mobile units do not have filters to separate the two frequencies, and thus cannot transmit and receive simultaneously. They operate in the simplex or "push to talk" mode, in which the receiver is disabled while a message is being transmitted, and must compete with one another for "air" time.

Table 9. Channel Assignment Options

Option	Voice Channel Loading	Voice Channel Wait Time, sec	Digital Channel Loading	Digital Channel Wait Time, sec
1. Original all-voice channel	0.723	9	--	--
2. Shared voice/digital channel				
a. Digital query and status; text by voice	0.530	3	--	--
b. Digital query, status, and limited text; remaining text by voice	0.396	1.4	--	--
3. Original voice plus dedicated digital channel				
a. Digital query and status; text by voice	0.365	1.9	0.04	<0.1
b. Digital query, status, and limited text; remaining text by voice	0.190	0.8	0.07	<0.1
4. Two voice channels	0.361	0.9	--	--

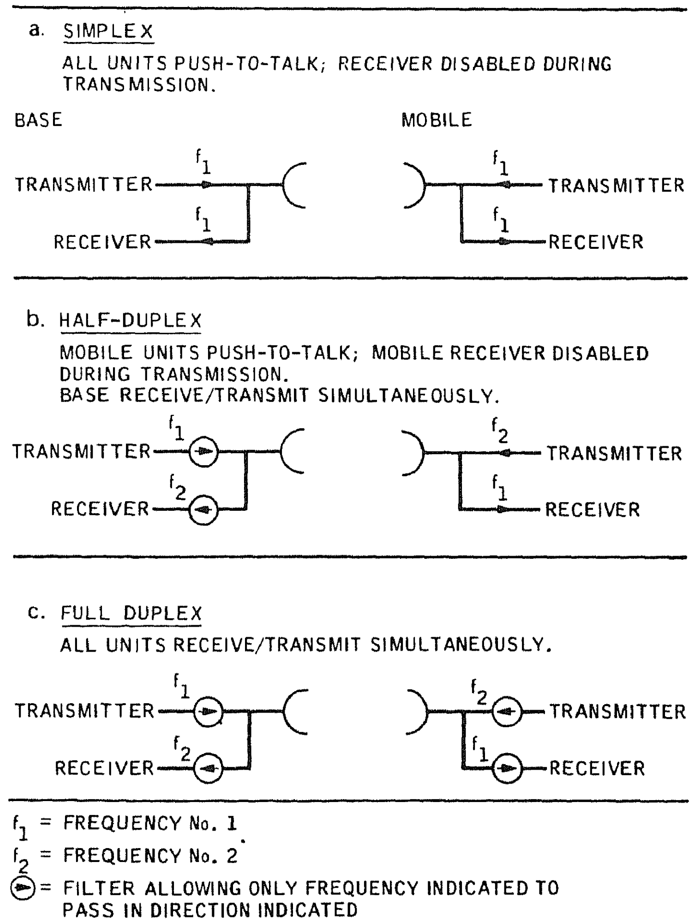


Fig. 10. Simplex–half duplex–full duplex links

- *Full Duplex.* The channel utilizes two frequencies and the base and mobile units are configured such that both can transmit and receive simultaneously.

If the existing system operates in the full duplex mode, there is no trade-off to be made. In the other two cases, however, there are special considerations involved with digital transmissions.

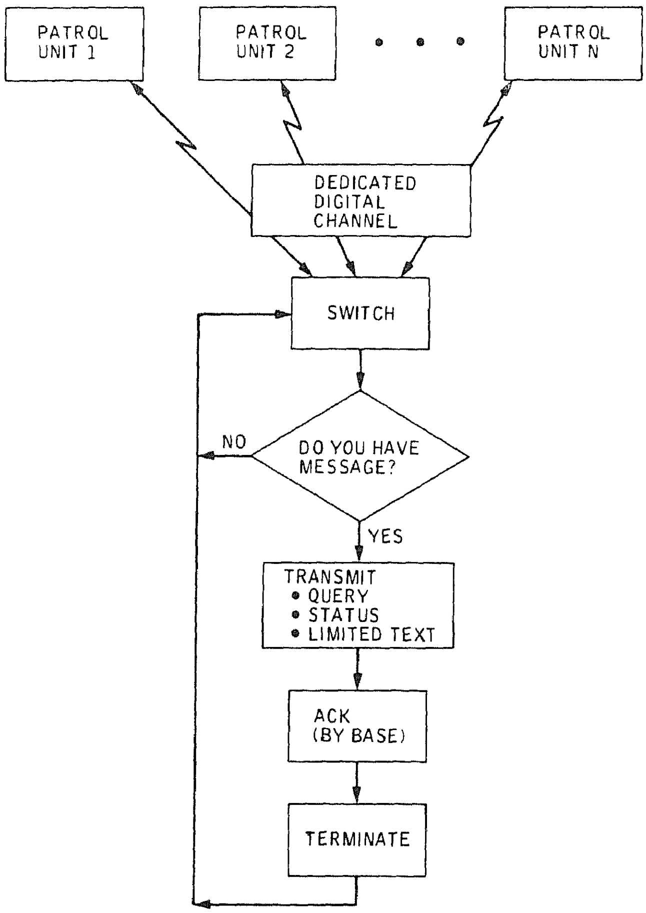


Fig. 11. Polling simulation

To prevent interference between mobile units in digital communications, a "base station busy" signal is used to prevent multiple transmissions, which result in lost messages. A simplex system does not permit such a signal; in small systems where patrol cars can normally hear the transmissions of other units and/or where the traffic is relatively light, digital messages might be handled satisfactorily without the "base station busy" signal. A simplex system would be feasible in such cases, although it would still be true that all transmitters, base and mobile, would be competing for transmission time.

With either the half duplex or full duplex systems the "base station busy" signal can be transmitted on the station's transmit frequency. Unless a separate subcarrier is used for this signal, however, it ties up the base station transmitter during incoming message periods so that outgoing messages cannot be sent.

In half-duplex operation, messages arriving at a mobile unit at times when that unit was transmitting would be lost. The probability of such occurrences should be quite low.

5.4 Mobile Unit Contention vs Polling

In a contention system all mobile units using a given channel are in direct competition for base station access on a "first come, first served" basis. That is, if one mobile unit is

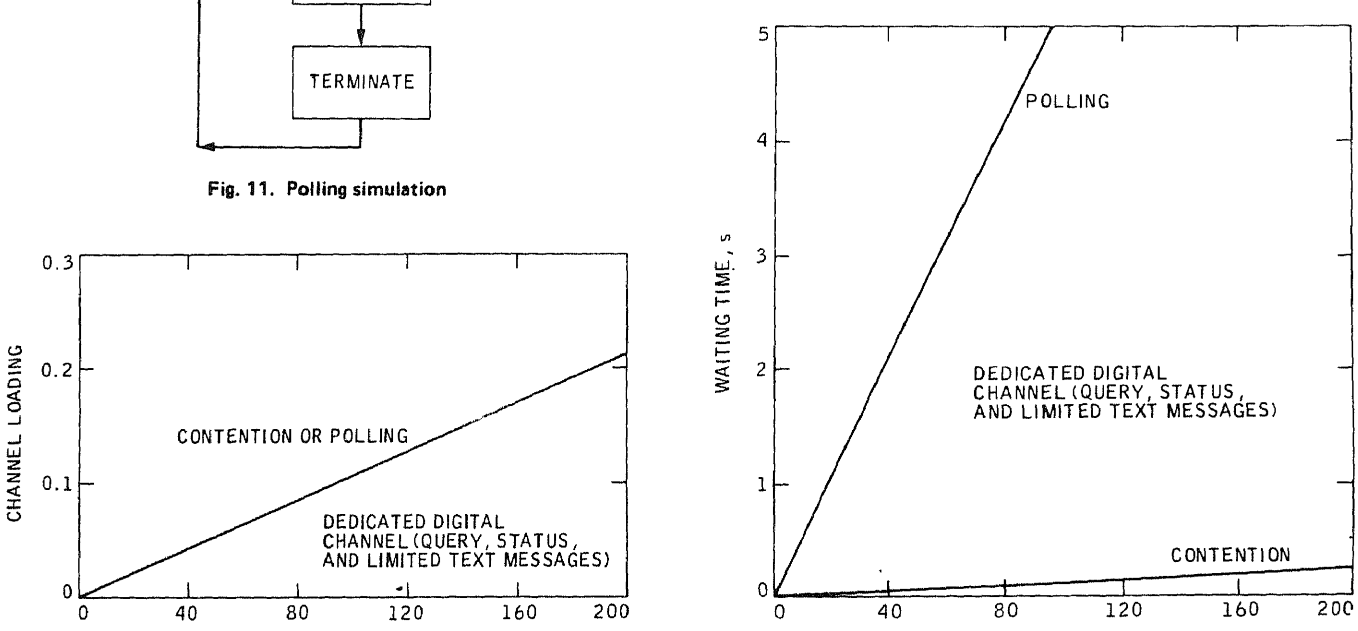


Fig. 12. Channel loading and waiting times with contention versus polled traffic control (mobile to base; transmission delay time = 50 milliseconds)

transmitting, no other can send a message until the channel becomes free. In a polling system, the base station allocates a time slot to each patrol unit and "polls" these slots in sequence to accept messages. The base station must transmit a "clear" signal to the mobile unit before that unit can transmit. In this mode of operation, no "base station busy" signal is required; the polling signals may be time-shared with the normal base station transmissions. Usually, a separate polling transmitter is necessary.

Since the polling versus contention mode has an important impact on system complexity, a computer simulation program was developed to obtain a comparison between the two for a moderately loaded uplink (mobile to base) channel (see Figure 11). The channel is dedicated to digital transmissions (queries, status messages, and limited text); system delay time was fixed at 50 milliseconds, which represents a lower bound value. The effectiveness of polling schemes is dictated by the delay parameter, and if any benefits are to be achieved, the delay time must be kept to a minimum. The analysis applies to an aperiodic mode of operation; that is, each unit in turn is given an opportunity to transmit a message, but if the unit has no message, the controller moves immediately to the next unit. This scheme avoids time wasted in a "fixed slot" polling protocol.

The results of the simulation are shown in Figure 12, which gives channel loading and waiting time, respectively. For the lightly loaded channel investigated, polling is not warranted. Subsequent investigations for very heavily loaded channels (ρ greater than 0.7) indicate that polling offers some reduction in waiting time, but the planner is not concerned with these applications. Block contention, in which several but not all units contend for the channel, provides some improvements over pure contention modes for intermediate and heavily loaded channels.

5.5 New Equipment vs Existing Equipment

There is nothing about the normal voice communications systems used for law enforcement that inherently prevents their handling digital transmissions without change (except for the addition of the specialized digital equipment). The planner would certainly prefer to keep the existing system in place. Some thought should be given, however, to potential sources of trouble, such as radios and receiver voting systems.

Current mobile radios, at least those procured some time ago, may have a significantly long response and turn-on time. Because of the high speed of digital transmissions, part or all of a message could be lost before the equipment was ready to accept signals. One way to deal with this difficulty is to use an adjustable preamble on the digital messages to give the equipment time to respond before the actual message arrives. This technique of course lengthens the transmission time for digital messages, but not to an unacceptable extent in most cases. A more serious drawback is that the turn-on delay reduces system throughput (total message traffic) in a turn-on, turn-off contention system.

It should also be recognized that misaligned or inadequately maintained radios can introduce severe attenuation and distortion into the channels used for digital communications, adversely affecting the performance of the data systems. This factor does not necessarily indicate a need for new equipment, but it should be taken into consideration.

Many mobile communication systems use receiver "voting" techniques to obtain the best possible signals at the base station. The incoming signals are monitored by several receivers, and the output from the receiver with the best received signal is selected and routed to the control area. Such a system can affect digital transmissions in two ways; there are switching transients when signals are switched from one receiver to another, and a notch filter is used to cut out part of the audio response for controlling receiver selection. The switching transient problem can be overcome by locking onto one receiver during the data burst and inhibiting voting during this period. An alternative would be to design burst error-correcting codes to ride through the votes. Still another procedure would be to receive and store the data from all the satellite receivers and implement a voting scheme with the stored data.

In many systems, signals are transmitted from remote receivers to the base station through leased telephone lines. These are often of the unconditioned type, perfectly adequate for voice and limited digital control tones, but quite inadequate for transmission of digital data at rates above 1000 to 1200 bits per second. This inadequacy results from many factors such as ambient noise, crosstalk, amplitude and phase vs frequency distortion. Consequently the planner should check on the quality of any leased telephone lines used in his system to determine how they will affect the performance of the digital system to be added.

5.6 Data Base Query Volume

It has been noted earlier that the implementation of a capability for direct data base queries from patrol units can be expected to multiply the volume of such queries by a factor of five or more. The planner needs to consider how this increase in volume will affect the equipment and procedures now being used to access local and remote data bases. The computer information systems being used by law enforcement agencies have

been designed to handle a certain volume of inquiries, and this volume was limited by the requirement for relaying voice queries from mobile units. If the volume is going to rise as much as indicated above, it is likely that the equipment now used to interface with data bases will be inadequate. It is also likely that the equipment at remote data banks such as state and NCIC (National Crime Information Center) files will be overwhelmed as more and more agencies acquire a capability for direct access by mobile units. The planner should consider not only his own needs for interface equipment, but the probable effect on the remote data base facilities. Consultation with the appropriate authorities is certainly in order.

5.7 Future Requirements vs Current Requirements

It has already been pointed out that the addition of a digital capability to a law enforcement communication system should not be looked upon simply as a better way of meeting current requirements. Requirements for digital techniques are certain to grow as new technology opens up new possibilities. Such capabilities as computer-aided dispatching, out-of-vehicle signaling, and automatic vehicle location monitoring are either technically feasible or will soon become feasible. The planner should be looking ahead to such possibilities as he selects a digital system configuration.

The most important element in accommodating future expansion of digital capability is the base station minicomputer. Many such computers are easily expandable, in that input/output capability can be added, memory can be expanded by the addition of modules, and the software system can be easily modified to handle new tasks. The planner should be sure that his system design includes provision for such expandability.

In summary, implementation of relatively high level digital system can and probably will have a strong impact on the overall command and control system and its operations. The planner should be aware of the potential impact and bound his feasibility planning to include the complete system, not digital equipments alone. A modeling device such as the command and control system simulation program described in Section 7 can be used to verify "before" and "after" operating characteristics of his system to identify potential overloading of system interfaces and personnel. Field tests of major subsystems involved in the upgrade should be conducted prior to any final commitment to the upgrade.

6. PLANNING GUIDELINES: PREPARING THE IMPLEMENTATION PLAN

The planner evaluating possible digital communications systems for his law enforcement agency will need to prepare an implementation plan for the system he selects. He may want to prepare implementation plans for two or more alternative systems he is considering, because only by preparing such a plan can he identify and estimate *all* the costs associated with implementing a given system. The plan not only serves to identify all the costs, but lists and schedules all the activities that will be required to acquire the system and place it into full operation. These can then be reviewed for their effects on other activities or planned activities of the agency concerned as well as on personnel management.

The implementation plan consists essentially of an overall schedule of activities and a funding plan. The line items on the overall schedule should include at least the following:

(1) Precontract phase
(2) Procurement
(3) Facility preparation
(4) Installation and checkout of equipment
(5) System demonstration and acceptance
(6) Personnel training
(7) Maintenance

Other items that may be required in certain cases include:

(8) Obtaining FCC license
(9) Local government agreements
(10) Data base connections
(11) Time-phased implementation (system not procured all at once)

The funding plan should include, beside complete cost estimates, a breakdown of expenditures by fiscal year from the start of funding to completion of operational capability. Estimates for yearly maintenance should also be given. The elements in the funding plan are generally the following:

(1) The local agency program management office
(2) Consulting or systems engineering support, if planned
(3) Procurement of equipment and software
(4) Facilities acquisition and preparation
(5) Logistics (training, spare parts, maintenance)

Examples will be given for two possible mobile digital communications systems, one a basic status-only system and the other a larger system including a full-text plus status capability in the mobile units. Only the essentials of the implementation plan are given in the examples; the planner may wish to add details.

Example I: Status-Only System

The system to be implemented is the following:

- There are 40 mobile units operating on a single half-duplex radio channel.
- Up to six digital "canned" status messages plus unit identification can be sent from the mobile unit. Acknowledgement by base station is both automated and manual.
- Digital messages share the voice channel.
- The dispatcher's display shows the status of the 40 units by colored and blinking lights.
- A printer near the dispatchers' desk logs all status messages with their times.
- Local funding will be used and the entire system will be implemented at one time.
- A single contract will be let to a vendor for all aspects of the system: hardware in base station and mobile units, training, and documentation.

The overall schedule of activities is shown in Figure 13 and is self-explanatory. The cost estimate is given in Table 10. For this example, the costs are not broken down by fiscal year. The elements in the cost estimate are defined as follows:

Program Management Office. This item covers salaries and office equipment for a three-person Program Management Office for the duration of the implementation period. This staff is responsible for preparing the Request for Proposal, evaluating the proposals received, interfacing with the selected vendor, and coordinating with the day-to-day police operations and local government personnel.

Travel. This item covers the travel required for consultation with personnel in cities that have implemented similar systems and the travel to the vendor's plant.

Table 10. Cost Estimates for Example I (Status-Only Upgrade)

Item				Cost
1.	Program Management Office			
	(a)	Senior police officer	17 months X $1900	$ 32,300
	(b)	Communications engineer	17 months X $1200	20,400
	(c)	Clerk typist	17 months X $675	11,475
			Total salaries	$ 64,175
			Employee benefits	19,252
			Total personnel services	$ 83,427
	Office equipment and supplies			5,000
			Total Program Management Office	$ 88,427
2.	Travel			3,000
3.	Facilities remodeling			5,000
4.	Procurement costs			
	(a)	Mobile terminals	40 X $700	$ 28,000
	(b)	Base station equipment		50,000
	(c)	Spares		8,000
	(d)	Engineering services, including training program		60,000
				$154,000
			Total estimate	$242,427
5.	Maintenance costs (per year)			$ 8,600

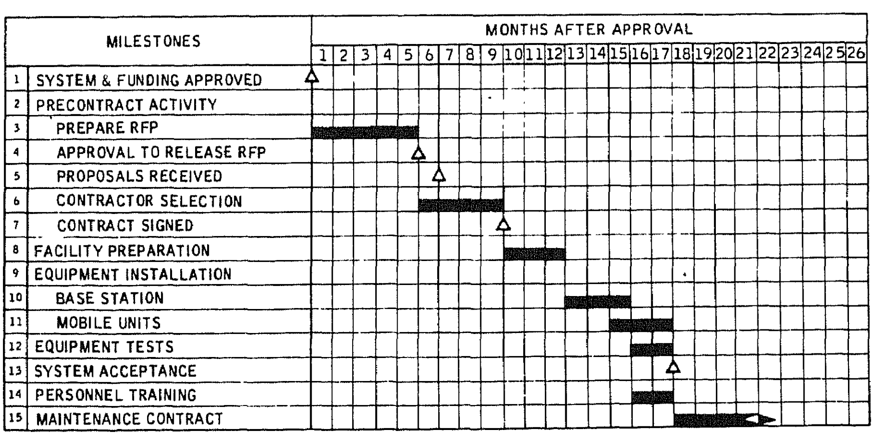


Fig. 13. Overall schedule of activities for Example I (status-only upgrade)

Table 11. Cost Estimates for Example II (Status, Full Text, Data Base Query)

Item				Cost
1.	Program Management Office			
	(a)	Senior police officer	21 months X $1900	$ 39,900
	(b)	Police officer	21 months X $1300	27,300
	(c)	Administrative analyst	1/2 X 21 months X $1500	15,750
	(d)	Communications engineer	21 months X $1600	33,600
	(e)	Data processing engineer	21 months X $1600	33,600
	(f)	Clerk typist	21 months X $675	14,175
			Total salaries	$164,325
			Employee benefits	49,298
			Total personnel services	$213,623
		Office equipment and supplies		7,000
			Total Program Management Office	$220,623
2.	Travel			$ 4,000
3.	Facilities remodeling			$ 10,000
4.	Procurement costs			
	(a)	Mobile terminals	60 X $3,000	$180,000
	(b)	Base station computers, software and peripherals		100,000
	(c)	Spares		25,000
	(d)	Engineering services, including training program		80,000
				$385,000
			Total estimate	$619,623
5.	Maintenance costs (per year)			$ 30,500

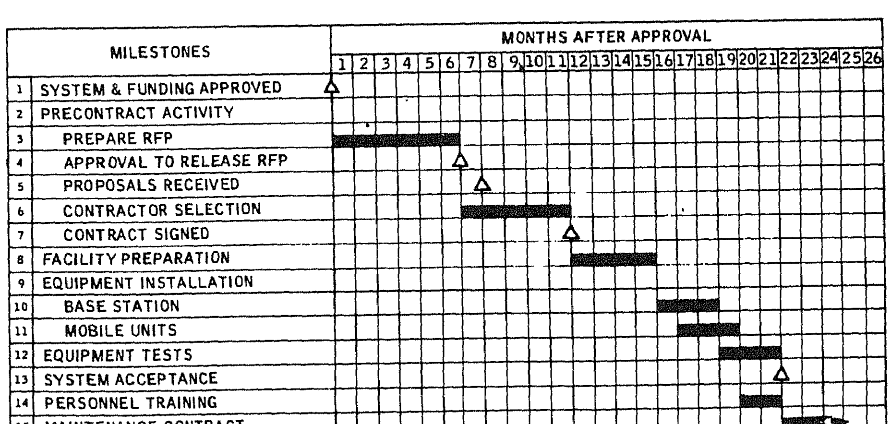


Figure 14. Overall schedule of activities for Example II (status, full text, data base query)

Facilities Remodeling. It is assumed that the existing dispatching room is adequate, but that some rearrangement of operating positions is needed and a wall must be erected for mounting the new status display board.

Procurement Cost. This item covers all mobile and base station equipment, including that required to interface with existing radio transmitters and receivers and the display board for the dispatching room. It also includes engineering, installation, and all tasks leading to acceptance of the system by the agency.

Example II: Status, Full-Text, Data Base Query

In this example, the system to be implemented is the following:

- There are 60 mobile units operating on two half-duplex radio channels.
- Full-text digital capability to and from the mobile units is provided, plus up to six "canned" messages and unit identification.
- Digital messages share the channels with voice messages.
- The dispatchers' display shows the status of the 60 units by colored and blinking lights.
- The system provides for direct data base inquiry from mobile units for wanted persons, license plate checks, and related data base information.
- Local funding will be used and the complete system will be implemented at one time.
- A single contract will be let for the complete system, including equipment, software, training, and documentation.
- The system includes equipment to interface with communication lines to existing data bank computers. No additional hardware or software is assumed to be required for access to data banks.

The overall schedule of activities for this example is shown in Figure 14. The cost estimates are presented in Table 11 with the breakdown by fiscal year given in Table 12. The elements in the cost estimate are defined as follows:

Program Management Office. This item covers salaries and office equipment for a 6-person Program Management Office during the implementation period. The staff is responsible for preparing the request for proposal, evaluating the proposals received, interfacing with the selected vendor, and coordinating with the day-to-day police operations and local government personnel.

Travel. This item covers the travel required for consultation with personnel in cities that have implemented similar systems and the travel to the vendor's plant.

Facilities Remodeling. It is assumed that the existing dispatching room is adequate but must be remodeled to provide display board mounting and separate areas for additional equipment. It is also assumed that additional area is needed for spares storage, system documentation, and supplies.

Procurement Costs. This item covers all mobile and base station equipment, including that required to interface with existing radio transmitters and receivers and a display board for the dispatching room. It also includes engineering, installation, and all tasks leading to acceptance of the system by the agency.

Items Not Included. The cost estimate does not cover the leasing of any necessary telephone lines for communication with data banks, nor any work required to expand or modify data banks.

The above examples of cost and schedule information are intended to illustrate typical implementation plans. Both examples could be significantly in error and should not be taken as representative of costs for any given system at any given time. The planner must develop his own estimates through discussion with other agencies that may have implemented systems similar to the one he is considering, and with vendors of equipment (see Table 1 for a partial list of agencies currently involved with digital communications programs.)

Table 12. Cost Breakdown by Fiscal Year, Example II (Status, Full Text, Data Base Query)

Item	FY 1	FY 2
Program Management Office	$126,070	$ 94,553
Travel	1,500	2,500
Facilities Remodeling	500	9,500
Procurement	0	385,000
FY Total	$128,070	$491,553
Accum.Total	$128,070	$619,623

7. PLANNING GUIDELINES: COST BENEFITS ANALYSIS

The final determination of what digital communication system to implement for a given agency will be strongly influenced by an overall evaluation of costs versus benefits. We can identify a set of benefits that can be expected to follow from the implementation of a digital capability in a given agency:

(1) Improved officer safety
(2) Shorter response time to citizen calls
(3) Reduced crime rate
(4) Improved "hit" rates
(5) Reduced load on patrol personnel
(6) Reduced load on base station personnel
(7) Reduced channel congestion and "wait" time
(8) Improved communication security

Obviously, not all of these factors, and certainly not the most important of them, can be expressed in dollar terms. Our approach to cost benefits analysis will be to compute dollar cost savings wherever possible and to evaluate the qualitative benefits that are associated with digital communications by means of a relative ranking technique.

Of the benefits listed above, items 5 and 6 clearly can be measured in terms of dollar costs, and items 3 and 4 can be estimated even though with greater uncertainty. Item 7 is essentially covered by the estimates for personnel loading (items 5 and 6). The other items are either measured in terms of reduced response time (1 and 2) to which no dollar value can be assigned, or can be evaluated only in qualitative terms (8). A relative ranking scheme is used to treat this latter category of benefits.

Few analytical techniques are available, however, that can handle satisfactorily the complex interactions among all the elements of a system that lead to reasonably accurate estimates even of personnel loading. The planner can arrive at such estimates by considering reductions in transmission time and projecting these to personnel loading, but a better approach is to consider the entire command and control system and determine how all its elements are affected by the new capability.

7.1 System Simulation

For the reasons given in the preceding section, we have developed a computer simulation of a law enforcement command and control system. This program is designed to simulate the actual operations of such a system under various design and loading assumptions. In this way, it determines the actual effect on base station and patrol unit personnel loading of decreased message transmission time, reduced channel loading, and other system parameters.

Figure 15 is a block diagram of this simulation of a law enforcement command and control system. It consists basically of two separate elements, representing the base station and the patrol units, respectively. Beginning with the base station sequence on the left, calls for service are generated and placed in a queue for the attention of the complaint board operator (CBO). Some calls are not passed to the dispatcher but referred to other elements of the agency, such as the detective bureau, for action. Those calls that are referred to the dispatcher form a queue to wait for the attention of the next available dispatcher. One or more dispatchers can be assumed, and the program maintains a continuous status on each so that it can determine when he will have completed his previous task. This status monitoring function also measures dispatcher loading (percentage of the total time he is handling calls, assigning units, acknowledging messages, etc.)

Once the call reaches the dispatcher, 30 seconds are allowed for the dispatcher to examine the information, determine what action is required, and select a patrol unit on the basis of patrol unit location and availability.

The next block represents the operation of contacting the selected patrol unit and giving it the assignment. The average time allowed for this block is 10 seconds; with a digital capability, the dispatch transmission time is reduced to 3 seconds.

A 60-second block of time is allocated for the preparation of the dispatcher's report on each call. The program accumulates these blocks to provide the total time the dispatcher spends on a call, including subsequent conversations with the patrol unit working the call.

The patrol unit model begins with a set of patrols, the number specified as an input to the program. At the beginning of the run, each patrol unit is assigned a status (normally "available"). The program monitors channel usage by all patrol units and thus "knows" when the channel is clear. When the channel is clear, the patrol unit sends a status message; this is assumed to require a fixed time of 3 seconds for voice and 1 second for digital.

The "dispatch call?" decision block is the link between the base station and the patrol unit with respect to the handling

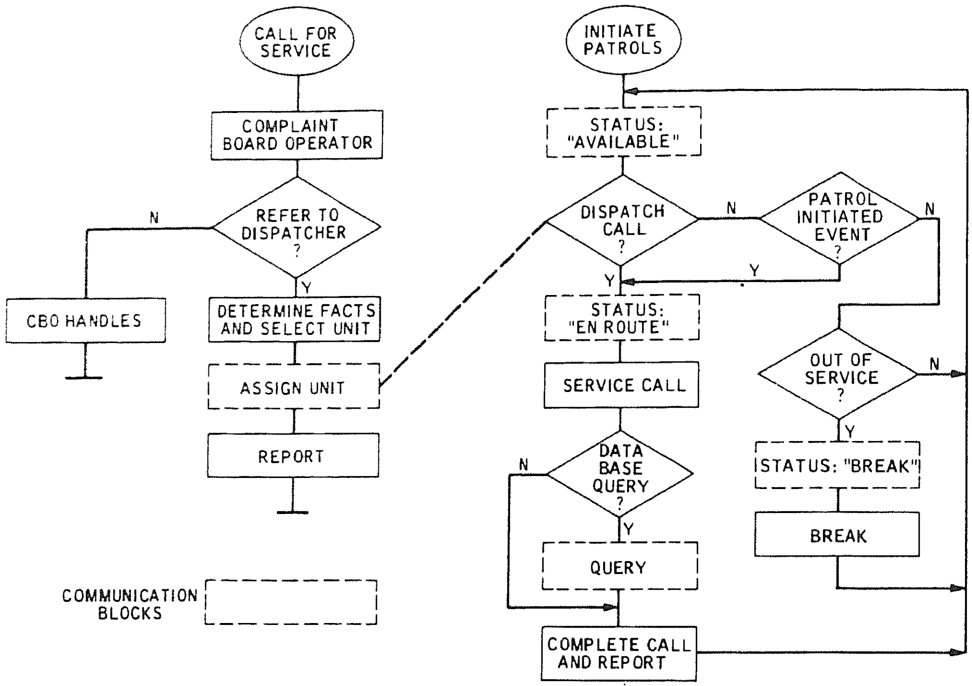


Figure 15. Command and control system simulation

of service calls. At this point, the patrol unit sequence checks the corresponding block of the base station sequence to determine whether or not a dispatch call for that unit exists. If there is none, the model then determines whether or not a patrol-initiated event is to be assumed at this time. The model uses a nominal value of three such events per 8-hour shift, assigned randomly.

If no patrol-initiated event is scheduled, the model next checks to determine whether the given patrol is scheduled for a break. If it is, the communications block is again used, except that the status reported is "on break" and the program changes the status of this patrol unit accordingly.

Returning to the "dispatch call" decision block, if there is a dispatch call for this unit issued by the base station sequence, the program again uses the communications block except that the status reported is "en route" (the program changes the status of this unit accordingly).

The time allowed by the program for completion of the service call by the patrol unit is randomly selected from an exponential distribution, with an average of 35 minutes.

There is some probability that a given service call will involve a data base query. If no query is involved, the program allows a 60 second block of time for preparation of a report and returns to the beginning for a new status assignment for the given patrol unit. If there is a data base query, the communication block is simulated, with the addition of a time increment for transmission of the query and receipt of the response. The time allowed is 20 seconds for voice and 5 seconds for digital.

7.2 Results of the System Simulation

Because the simulation model addresses the operation of the complete command and control system beginning with incoming service calls, and because it represents statistically varying parameters by random selection from realistic probability distributions, it can make realistic estimates of channel loading, wait times, and personnel loading under various assumptions. In particular, it can provide realistic estimates of the quantitative benefits to be expected from the addition of a digital communication capability to an existing voice-only system.

The major results from an initial run are shown in Table 13, together with the assumptions regarding the system modeled. This table represents the results of simulating 6 hours of system operations.

The significant differences between the voice-only case and the voice plus digital case are seen in the dispatcher loading (reduced by half), reduced channel loading, and the patrol utilization factor (time on patrol).

7.3 Cost Benefits Evaluation

As noted earlier, some of the benefits resulting from digitization lend themselves to computation in dollar terms and others are difficult or impossible to quantify. Of the parameters listed in Table 13, one can be translated into dollars: dispatcher loading. In a system with only one dispatcher no dollar saving can be made (although the change from intolerable overloading to easily handled work load is a benefit), but where there may be several dispatchers the change to voice plus digital communications may permit the elimination of one or more dispatcher positions.

All benefit evaluations discussed here will assume a 5-year life for the digital system; consequently annual savings are multiplied by 5 to derive a total dollar benefit. In the case of a dispatcher, dollar savings are estimated to be:

Direct salary	15,000 X 5 =	75,000
Employee benefits at 25%	3,750 X 5 =	18,750
Total 5-year saving (per shift)		$93,750
Total 5-year saving (a factor of 4.5 is used for 24 hour, 7 day coverage)		$421,900

This calculation does not allow for salary increases over the 5-year period; these would increase the amount of the saving.

For the system modeled in the simulation, a reduction from two to one dispatcher was assumed. In the case of the patrol units, a saving can be calculated assuming that present patrol time must not be reduced (this policy may or may not be a firm requirement of the individual agency, but it is traditionally used by many planners; see Larson, *Urban Police Patrol Analysis*). Using a value of $15 per patrol unit hour, the difference between the 57 percent time on patrol with the voice-only system and the 59 percent time on patrol with the voice plus digital system translates into dollar savings as follows. Assuming that patrol fleet size is not reduced (only a fraction of one car could be removed), but that the number of patrol hours is held at the original level:

59 - 57 = 2 percent more time on patrol

0.02 × 8 = 0.16 hours per 8-hour shift per unit

Table 13. Results of JPL Simulation Model Run

Assumed system for the model run:

20 patrol units

1 full-duplex channel

I service call per 6 minutes (mean value)

Parameter	Voice Only	Voice Plus Digital*
Channel utilization, percent**	46	16
Wait time for channel, seconds	3.3	0.4
Dispatchers	2	1
Dispatcher loading, percent	48 (avg)	49
Wait time for dispatcher, seconds	39	35
Units on patrol, average	11.3	11.8
Percent time on patrol, all units	57	59

*Assumes full digitization of status, query, and dispatch messages.
**Base to mobile.

3 × 365 × 0.16 × 20 = 3,504 hours per year for all patrol units

3,504 × $15 = $52,560 per year savings

= $262,800 savings in 5 years

The total direct cost savings based on a 5-year life are:

Reduced dispatcher labor costs	$421,900
Savings in patrol costs	$262,800
	$684,700

The added cost of the voice plus digital system was estimated at $619,623 (see Table 11) for a 60-unit fleet, or $491,290 for a 20-unit fleet. This cost must be increased by the cost of maintenance over a 5-year period, which is taken at 10 percent (per year) of the original equipment costs of $168,330, based on Item (4) of Table 11 less item (d) (adjusted for 20 rather than the 60 units shown in Table 11): over a 5-year period, maintenance cost will total $84,166, giving a total system cost of $491,290 + $84,166 = $575,456. Comparing this cost to an estimated saving of $684,700 gives the approximate cost benefits of the implementation of digital communications.

The above simple example illustrates the procedure for computing cost benefits. For larger systems, fractional savings in manpower can be accumulated to permit the reduction in positions,with accompanying larger dollar savings.

7.4 Overall Cost-Performance Evaluation

While cost benefits are an important criterion in evaluating a potential communication system upgrade, the planner is often asked to prepare an overall rating for each system configuration under consideration, including relative system performance as well as costs. This can be done by means of a weighting technique, which assigns numerical factors to potential system capabilities to provide some degree of comparative measurement of the value of systems with different characteristics.

The following brief discussion is based on material prepared by Hughes Aircraft Company, Fullerton, California.

A set of weighted characteristics is given in Table 14. The weighting factors are not arbitrary but are based on a series of judgments and calculations, not given in detail here. A set of agency goals is established (for example, prevention/suppression of crime, investigation/apprehension of criminals, maintenance of public order, and public services), and assigned relative weights (which add up to 1.0). Agency functions, such as management/planning, supervision/control, and field operations, are also identified and weighted. These two sets of factors are then interacted (that is, how much does supervision contribute to public services as against investigation/apprehension, and so forth) to produce a set of weighting values for each function according to the way it supports the goals. A set of system features, or capability items, is established (see Table 14). The weighting values are assigned to the set of system features, resulting in the final numerical values in Table 14. We should emphasize that these relative-value numbers result from a series of judgments made jointly by technical and police professionals, brought out to a simple column of figures by multiplication.

Table 14. Relative Weighting of System Performance Capabilities

Item	Relative Weight
1. Radio congestion	0.08
2. Query capability	0.10
3. Response time	0.10
4. Support officer in trouble	0.18
5. Monitor unit location/status	0.05
6. Dynamic re-deployment	0.07
7. Management planning	0.07
8. Unexpected occurrence control	0.11
9. Resource utilization	0.11
10. Clarity of dispatch messages	0.07
11. Data collection	0.06
	1.00

To support a comparison of systems, the relative presence of each item in each system is determined (columns 2 and 4, Table 15). These must add up to 1.0 for all systems compared for any one line item. The weights of the items (column 1) are multiplied in (columns 3 and 5) and totals for all items taken for each system. These totals measure the benefits of the systems according to the weighted capability items, and can be used to rank the systems on the basis of benefits.

Cost values can be similarly compared, and, when cost and performance qualities have been suitably weighted, the systems may be ranked on the basis of cost *and* performance, as shown in Table 16.

Other desired items of capability may and probably should be derived, valued, and calculated on the basis of the planner's own department, using this technique. The results might confirm an intuitive judgment, or they might not; in any case, they are based on visible and agreed-on rules and inputs. The full details of the work-up tables should be presented along with the final ranking values so that the decision makers are fully aware of the factors that cause a given system configuration to rank above or below its competitors. The planner also may wish to establish a lower bound for certain critical features (for example, officer safety, or response time) and call attention to systems that do not meet minimal standards.

The above example illustrates a procedure for ranking and comparing system configurations on the basis of general performance and cost goals. The planner may wish to add or delete certain criteria, or to assign different weighting values, but we believe that he will find the method useful in evaluating potential upgrades.

Table 15. Relative Performance Rankings of Voice-Only System and Voice-Plus-Digital System

Item	1 Relative Weight*	Voice-Only 2 Value	Voice-Only 1 x 2	Voice-Plus-Digital** 4 Value	Voice-Plus-Digital** 1 x 4
1. Radio congestion	0.08	0	0	1.0	0.08
2. Query capability	0.10	0.4	0.04	0.6	0.06
3. Response time	0.10	0.3	0.03	0.7	0.07
4. Support officer in trouble	0.18	0.4	0.07	0.6	0.11
5. Monitor unit location/status	0.05	0.3	0.02	0.7	0.03
6. Dynamic redeployment	0.07	0.3	0.02	0.7	0.05
7. Management planning	0.07	0.4	0.03	0.6	0.04
8. Unexpected occurrence control	0.11	0.3	0.03	0.7	0.08
9. Resource utilization	0.11	0.4	0.04	0.6	0.07
10. Clarity of dispatch message	0.07	0.4	0.03	0.6	0.04
11. Data collection	0.06	0	0	1.0	0.06
System performance rank**			0.31		0.69

*Column 1 sums to 1.00 (see Table 14)
**Status plus full-text plus automatic data base query

Table 16. Relative Overall Rankings of Voice-Only System and Voice-Plus-Digital System

Item	1 Relative Weight*	Voice-Only 2 Value	Voice-Only 1 x 2	Voice-Plus-Digital** 4 Value	Voice-Plus-Digital** 1 x 4
1. Performance	0.7	0.31	0.22	0.69	0.48
2. Cost	0.3	0.45	0.13	0.55	0.17
System overall rank			0.35		0.65

*Column 1 sums to 1.00
**Status plus full-text plus automatic data base query

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APPENDIX A

COMPARISON OF DIFFERENT AVAILABLE MOBILE DIGITAL COMMUNICATIONS SYSTEMS

This appendix consists of a set of tables comparing the features and characteristics of mobile digital communications systems offered by six different manufacturers. It was made available by the Texas A & M Center for Urban Programs at the Urban Technology Conference on Mobile RF-Digital Communications held at Arlington, Texas, March 11-12, 1974. The tables present comparative data on the following system elements:

(1) The overall system

(2) The mobile terminal

(3) The mobile printer

Note that some of the systems or elements were still under development at the time the table was compiled, and that some information was not available; anyone interested in the current status of such items, or of systems not described, should check directly with the manufacturer (a list of vendor contacts is given in Appendix C).

A narrative description of a single representative system is presented in Appendix B.

Manufacturer	System	Basic suitability	Easily expanded	Interfacing with existing system: With simplex, duplex, half-dup.	Interfacing with existing system: With existing voice, radio	Interfacing with existing system: Time share with voice[2]	Interfacing with existing system: Requires dedicated data channel	Delivered	O s
Atlantic Research Corp.	ARCOM	Typically 60 vehicles About 100 maximum	Yes	Yes	Yes	Yes	No	3	
Coded Comm.	Star	15 vehicles up	Yes	Yes	Yes	Yes	No		
E-Systems	Digicom								
	8000	Unlimited	Yes	Yes. Full duplex	Yes	Yes	No	Yes	
	DC10	Unlimited	Yes	Yes	Yes	Yes	No	Yes	
	DC300	Unlimited	Yes	Yes	Yes	Yes	No	Yes	
Kustom	Radcom Comcen	Up to 300 mobile terminals (Can support multiple and multiple data bases)	Yes	Yes	Yes	Yes	No	Yes	
Motorola	Modat[1]	[1]To be defined	Yes	Yes	Yes	Yes	No	Yes	
Sunrise Electro-Service Corp.	Moscan	Up to 1000 mobile terminals per radio channel; avg. eight 256 char. msg./term./hr.	Yes	Yes	Yes	Yes	No	Yes[15]	

[1]The Motorola Modat alphanumeric terminal system is currently under development, and many details have not yet been released. Software support has been fully developed and is available.
[2]It is recommended that channels carry digital traffic only.
[3]Currently under development.

[4]The scope of t
[5]Capability of i
[6]Eventual com
[7]Effective data

Manufacturer	System	Unit cost	Alphanumeric keyboard	Alphanumeric display	Remote display[2]	Message editing	Report generation	T S
Atlantic Research Corp.	ARCOM	$1800	Yes. 50 keys[1]	16 char. LED	Yes	Yes	Yes, up to 80 char./transmission	8C
Coded Comm.	Star	$ 691						
E-Systems	Digicom							
	8000	$3500	Yes. 51 keys	256 char.	Yes	Yes	Yes	2!
	DC10	$ 900	No	3 char.	Yes	Yes	No	
	DC300	$3000	Yes. 48 keys	64 char.	Yes	Yes	Yes	6
Kustom	Radcom Comcen	$3200	Yes. 39 keys Yes. 39 keys	256 char. Plasma displays	No. Audio tone signal alert.	Yes	Yes Yes	2
Motorola	Modat	$3000	Yes. 40 keys	32 char.	Yes. Audio tone signal alert option.	Yes	Yes	6
Sunrise Electro-Service Corp.	Moscan[10]	$2095	Yes. 51 keys	30 char.	Yes	Yes	Yes	:

[1]The ARCOM MCT-16 keyboard is non-standard and designed to permit users not familiar with the standard typewriter keyboard to operate the terminal with ease.
[2]The received message can be displayed by command from base station.

Software							
Operating software	Applications software	Custom tailoring for user need	Report generation[4]	Polling techniques	Direct data base inquiry and response	Terminal-to-terminal digital communication capability	Multiple (inquiry function)[5]
Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Optional	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Optional	No	Yes	Yes
Yes	Yes	Yes			Yes	Yes	
Yes	Yes	Yes	Yes Additionally provided	No	Yes (Multiple)	Yes	Yes
Yes	Yes	Variety of software pkgs avail.	Planned	No	Yes	If required	Yes
Yes	Yes	Yes	Yes	Yes[16]	Yes	Yes	Yes

the Management Information function performed or planned by the systems differs widely.
f inquiry by name, social security number, vehicle number, vehicle registration number, etc.
nputerized dispatching with manual complaint entry.
ta rate including redundancy = 600 bps.

Transmitted message		Received message					
Storage	Display	Length	Display	Indication	Changeable address	Key lock switch	Transmit mode[3] indication
30 char.	16 char.	16 char.	16 char.	Yes (tone, horn or flashing light)	Yes	No	Yes Flashing display indicates trans.
					Yes	Optional	Yes
256 char.	256 char.	256 char.	256 char.	Tone/indicator	Yes	No	Yes
0	0	3 char.	3 char.	Tone	Yes	No	Yes
64 char.	64 char.	64 char.	64 char.	Tone/light	Yes	No	Yes
256 char.	224 char.	256 char.	256 char.	Yes (Tone alert)	Yes	Yes	Yes
64 char.	32 char.	64 char.	32 char.	Yes (Tone)	Yes	No	No
256 char.	32 char.	256 char.	32 char.	Yes (Light/tone select - blink-steady-none)	Yes	Optional	Yes

3 Indicates that the mobile terminal is transmitting a message.
4 Indicates that the mobile terminal did not receive an acknowledgement indication.
5 All transmissions from the mobile terminal are identified by the assigned mobile terminal ID.

Computer asst. dispatch	Data rate	Adapt. to different data bases[8]	Hit display[9]	Status display[10]	Line control contention mode[11]	Modulation technique	Mo
Yes	600 bps[7]	Yes	Yes	Yes	Yes	Coherent FSK[12]	
Yes						Coherent PSK	
Yes	1200 bps	Yes		Yes	Yes	PSK	
Yes (limited)	300 bps	Yes	Yes	Yes	Yes	FSK	
Yes	300 bps	Yes	Yes	Yes (Alphanum plus color)	(plus polling)	FSK	
Yes	185 char./sec	Yes	Yes	Yes	Yes	APSK	
Yes[6]	800 bps or more	Yes	Yes	Yes	Yes	Differential PSK[13]	
Yes	700 char./sec	Yes	Yes	Yes	Yes	PASK[17]	

[8]Adaptability to different data bases, such as NCIC, FCIC, state computer info. centers, metro. info. centers, etc., which in general might have different communication line spec., different data rate, different character coding, etc.

[9]As soon as a "hit" is reported by the data base computer (remote or local), the message is dispatched automatically by the base station computer to the officer via the mobile terminal and is displayed at the dispatcher console and/or logged for later reporting and statistical use.

[10]The status of all available mobile units is continuously displayed at the dispatcher console and is continually updated by the base station computer system.

[11]The terminal system is designed (in the Radcom-1, Modat & ARCOM systems) to share existing voice radio channels, operating in contention mode. In the Modat system, precedence is always yielded to the voice traffic. Through channel sensing, the Radcom-1 and ARCOM systems prevent pre-emption of a voice transmission by a digital message.

ransmit ication[4]	Auto ID[5]	Acknowledge-ment	Automatic retransmission	Channel sense[6]	Dual buffering[7]	Weight	Swivel capacity	Glare avoidance
s	Yes	Yes	Yes	Yes	No	4 lb	Not needed	Yes
		Yes	Yes	Yes				
		Yes	Yes	Yes	Yes	20 lb	Different mounting con-figurations	Yes
		Yes	Yes	Yes	No	7 lb		Yes
		Yes	Yes	Yes	No	17 lb		Yes
		s Automatic	Yes	Yes	Yes	17 lb	Yes	Yes
	Yes	Yes	Yes	Yes		Light	Yes. Also raise/lower	Yes
Yes	Yes	Yes Auto. & manual	Yes	Yes (Selectable carrier-data-none)	Yes	71 lb	Yes. Also raise/lower	Yes

[6]Channel activity is sensed for non-interference transmission.

[7]Allows message reception even as a message is being transmitted.

[8]Function keys simplify message composition and data entry for certain fixed format messages (usually user assignable). Also transmission time for such fixed format messages is shorter.

[9]Semi-autom transmissior

[10]Additional

[11]With altern

MOBILE DIGITAL SYSTEM CHARACTERISTICS

...ation ...de	CPU: power fail/start capability	Line printer[14] Rate, lines/min	Line printer[14] Size, char./line	Mobile terminal: Alphanumeric terminal	Mobile terminal: Electronic display	Mobile terminal: Hard copy printer	System	Manufacturer
...nc	Yes	Two models 60	80	Yes	Yes (LED)	Availability projected	ARCOM	Atlantic Research Corp.
...c							Star	Coded Comm.
							Digicom	E-Systems
...nc	Yes	Customer specified		Yes	Yes	Optional	8000	
...ync	Yes			Yes	Yes (LED)	Optional	DC-10	
...ync	Yes			Yes	Yes (CRT)	Optional	DC-300	
...nc	Yes	Three models 60	80	Yes	Yes (plasma)	Optional	Radcom Comcen	Kustom
		60	132					
		300	132					
...ync	Yes	Two models 135	80	Yes	Yes (LED)	Optional	Modat	Motorola
		300	80					
sync	Yes	Cust. spec.	Cust. spec.	Yes	Yes	Optional	Moscan	Sunrise Electro-Service Corp.

[12]The transmission is synchronous during the message and asynchronous between messages.
[13]The Motorola system will be designed to operate with existing Motorola radio equipment.
[14]Line printer at the base station; normally used for message logging of incoming and outgoing messages.
[15]Digital communications system in radio services other than public safety.
[16]A programmable feature.
[17]Sunrise's Moscan system interfaces with all modern radio equipment.

MOBILE TERMINAL EQUIPMENT CHARACTERISTICS

Function keys[8] Number	Function keys[8] User coded	Status keys	Emergency key	Entry[9]	System	Manufacturer
10	Yes	Special ten-key followed by status code	1	Semiauto	ARCOM	Atlantic Research Corp.
4	No	8	1		Star	Coded Comm.
					Digicom	E-Systems
9	Yes	9	1	Automatic	8000	
6	Yes	6	1	Automatic	DC-10	
7	Yes	4	1	Automatic	DC-300	
7	Yes	4	1	Semiauto	Radcom[1] Comcen	Kustom
53[11]	Yes	5	1	Automatic	Modat	Motorola
51[11]	Yes	10	1 (Remote emergency trigger)	Auto or semi-auto	Moscan	Sunrise Electro-Service Corp.

...ic entry: the transmit key (XMIT) has to be actuated after pressing a function key to initiate
...of the status message. Automatic entry: pressing the function key initiates transmission also.
...atures include forward error correction and PL tone muting.
...e keyboard.

MOBILE PRINTER CHARACTERISTICS

Manufacturer	System	Optional extra	Remote command operation capability[1]	Print rate	
				Lines/sec	(
Atlantic Research Corp.	ARCOM	Available in the near future.	Yes	2.5	21 (li
Muirhead, Inc.	Mercury IV	The Mercury IV mobile facsimile system provides fax transmission of messages, documents, and photographs over existing radio or telecom channels.		Resolution; 90 lines/in. Automatic operation. 4 hr continuous op. per roll c	
E-Systems	Digicom 10				
	300	Yes	Yes	2.0	16
	1200	Yes		4.0	32
Xerox		The Xerox printer is used with the Xerox 530 computer and may be interfaced with most other equipment. (Example – the GE installation in Shreveport.)		0.8	36
International Business Machines	2976	Only the mobile printer is available on the IBM mobile terminal for a hard copy reception of messages.		2.5	21
Kustom	Radcom[1] Comcen	Yes	Yes	3.5	16
Motorola	Modat	Yes	Yes	Mechanically identical to Mot teleprinter 100 WPM	36

APPENDIX B

DETAILED DESCRIPTION OF TYPICAL EQUIPMENT FOR MOBILE DIGITAL COMMUNICATIONS

This appendix describes the following typical equipments required for a mobile digital communications system:

1) The mobile digital terminal installed in patrol cars
2) The dispatcher's display terminal
3) A supplementary status-only dispatcher's display terminal
4) The base station line printer
5) The mobile terminal line printer (optional)

No descriptions are included of the base station controller, the core of which is the minicomputer, nor the software required for the controller to perform its functions. The minicomputer is a standard general-purpose machine not specifically designed for communications use, and the software description would be too specific to a given system to be useful in a document of this nature.

The items described here are specified hardware items manufactured by the Kustom Electronics Company, but the functions performed and the overall mode of operation are typical of most digital communications equipment in use by law enforcement agencies at present. The descriptions are included to provide a more detailed picture of how such a digital communications system operates.

1. The Mobile Digital Communications Terminal

The mobile communication terminal provides a means for messages to be transmitted and received in digital form, allows automated direct data base inquiry and response, and permits simple mobile unit status entry, update, and maintenance.

The main functional components of the mobile terminal are an alphanumeric keyboard, a solid-state alphanumeric display panel, receive and transmit message memories (called buffers), an internal power supply, and a specially designed modem (modulator/demodulator) for interfacing the terminal to the user's existing mobile radio.

Keyboard and terminal operation

Messages to be transmitted from the mobile unit are entered by the operator into the mobile terminal using the alphanumeric keyboard. Thirty-nine alphanumeric keys are provided (A-Z, 0-9, period, comma, slash). Messages entered into the terminal are displayed for the operator's verification; editing is done using the cursor controls (single space up, down, left, or right shifts). The next character to be printed appears in the position on the display indicated by the cursor.

After message composition and any required editing, transmission is initiated when the operator presses the TRANSMIT key.

A CLEAR/DISPLAY key allows the operator to clear any message no longer required to be displayed and to display a new message received by the mobile terminal. Received messages are not automatically displayed; the operator must request display of the received message by pressing the CLEAR/DISPLAY key. An exception occurs when a received message contains a remote action command from the base station controller. Then the received message can be displayed, or automatically duplicated, on the mobile printer; some other action, such as sounding the vehicle's horn, may occur. The message displayed on the mobile terminal will be duplicated on the mobile printer (if this option has been provided) when the operator presses the PRINT key. Received messages may be manually acknowledged by pressing the ACK key. Pressing either the TRANSMIT or the ACK key places the mobile terminal in an auto-transmit mode, and all operation of the terminal is then automatic. The auto-transmit mode permits a message to be transmitted, automatically, up to five times if the message is not acknowledged by the base station controller within some prespecified time, typically 2 seconds.

Controls are provided for varying the keyboard lighting and panel display intensity. A key-operated power switch prevents unauthorized operation of the terminal. All messages received by a mobile terminal contain information identifying single, group or all-unit calls. The unit identification number is set by inserting a hard-wired key into a slot in the rear of the terminal, and two thumb-wheels are used to set the two-digit group code. Only messages containing the proper group and unit identifiers will be accepted by a mobile terminal and made available for display. Selective addressing is also possible for outbound messages from a mobile terminal. Seven FUNCTION keys, coded by the user, denote that the message which follows contains special text. To perform a name check, for example, the user presses the NAME CHECK coded function key, enters

the name using a predefined format, and presses the TRANSMIT key.

Four STATUS keys are available. When the status categories have been coded, simply pressing any one of the STATUS keys automatically enters that status into the mobile terminal, and then pressing the TRANSMIT key initiates its transmission to the base station controller.

Pressing a double-size, two-position, mechanically locking EMERGENCY key automatically places the terminal in "emergency" status. The terminal operator may enter any additional data he desires and then, by pressing the TRANSMIT key, send the emergency message to the base station controller.

Upon receipt of any correctly addressed message, the mobile terminal verifies the message by parity checks over each character. Only error-free messages are accepted and immediately acknowledged. An incoming error-free message is held in a receive message buffer until the operator requests its display. Dual buffering of input and output messages permits a message to be received and held even while another message is being entered using the keyboard.

Accepted messages are immediately and automatically acknowledged by the mobile terminal; no manual action is required. In some cases, the base station controller may issue a command to a mobile terminal requesting only internal status and control information. These interrogations are automatically acknowledged and answered by the mobile terminal.

Message and status display panel

The 256-character solid-state plasma panel display contains 8 lines, each with 32 characters. The upper seven lines provide a 224-character display for transmitted and received message texts. The eighth line presents 32 characters of status information, serving as a mobile unit status indicator. The status indicator also provides either a MESSAGE, TRANSMIT, or RETRANSMIT indication, along with the indication F/Sxx. MESSAGE indicates to the operator that a message has been received and accepted by the mobile terminal, is stored in the receive message buffer, and is available for display and/or printing. TRANSMIT indicates that the mobile terminal is in the auto-transmit mode, while RETRANSMIT indicates that the mobile terminal did not receive an acknowledgement within the five transmission limit, and it is necessary for the operator to press the TRANSMIT key again. F/Sxx indicates the present numerical function and numerical status code of the mobile terminal, which is automatically included as a part of each message transmitted. Each character in the display is 0.20 in. wide by 0.28 in. high, in a panel viewing area 9.18 in. wide by 3.38 in. high.

Message structure and internal modem

The character information code used for message transmission is the 7-bit ASCII code. Only a subset of that code is used, forming a 6-bit code with a seventh parity bit for each character. Transmitted messages may contain up to 224 characters of text, both unit and group codes, and control and status information.

Essentially a functional duplicate of the base station encoder/decoder, the specially designed modem in the mobile terminal operates at a bit rate of either 1300 or 867 bits/sec, depending on the frequency of the audio carrier, which is either 1950 or 1300 Hz. The modulation method used is synchronous audio phase-shift keying (PSK) with absolute phase referencing. Synchronization is obtained by including a pilot-tone reference subcarrier on the audio signal.

Using a 1950 Hz audio carrier, with a bit rate of 1300 bits/sec, a 224 character message requires approximately 1.5 sec for transmission. At 867 bits/sec, 2.25 sec would be required. These times correspond, respectively, to effective data rates of 1045 bits/sec or 149 characters/sec, and 700 bits/sec or 100 characters/sec. Note that when the system operates at a rate of 867 bits/sec, it violates the FCC two-second rule if a 224-character message is transmitted. A carrier sensing technique is used to test radio channel occupancy prior to transmission.

Mobile radio and power supply connections

A permanent interface cable is attached to the user's mobile radio, which provides the connections required to the audio portion of the mobile radio for data transmit and receive, as well as transmit control and carrier sense connections to the internal circuitry of the mobile radio. The interface cable is field-matched to the characteristics of the particular mobile radio, thus allowing any of the user's mobile terminals to be used in that vehicle. Connections to the automotive power supply, which provides 12 volts DC, and negative ground are also required; these leads are contained within the interface cable. The unit weighs 17 lb and has the following dimensions: 10 3/16 H × 13 1/2 W × 9 7/8 D.

2. The Dispatcher Display Terminal

The dispatcher display terminal is used for controlling the deployment of mobile units. It is an operator-controlled display terminal for transmitting and receiving information to and from the base station controller. The terminal consists of a detachable keyboard, a 12-in. (diagonal measurement) CRT display, and a character generator, memory, programmable input/output processor unit, and power supply.

The unit displays the status of mobile units and other system resources, and is used by the dispatcher for routing information and dispatch messages to the operators of mobile units, via the mobile terminals. The dispatcher may also retrieve detailed status information for any mobile unit, and make inquiries into local and remote data bases in a manner similar to that of a mobile terminal.

Terminal operation

The terminal is operated in a dual-screen mode, and up to nine fixed message formats are available to simplify data entry operations. One of the formats simulates the operation of a mobile terminal. The other eight are defined by the user, and depend on the system application.

A cursor is always visible on the CRT screen, indicating the next character position to be entered or transmitted. The cursor may be moved by entering a character, tabbing, or using the cursor control keys. When the operator initiates a transmission, the cursor will reposition itself to the beginning of the format area and move as the message is transmitted, until the end of the format area is reached. A transmission request will deliver information only from the format area of the message being sent, even if the cursor has been moved beyond the boundary of that area to some other portion of the CRT screen.

Control functions are used by the terminal operator to specify the area of the screen to be worked in. After choosing CONTROL A or CONTROL B, the cursor goes to the first working position of the appropriate area.

Transmission from the terminal to the central processor of the base station controller is initiated by pressing the EOM (end of message) key, which causes all the text in the current format area to be transmitted. The operator may abort any operation at any time by pressing the ESC (escape) key, which clears the format area, displays the mobile terminal format, and repositions the cursor.

Any message format in the system can be recalled by keying Lx, where x is the number (1 to 9) of the desired format.

A function request, obtained by typing Fx, where x is the number of the desired function, allows the operator to simulate mobile terminal operations. Text is entered exactly as for a mobile terminal.

Status information is retrievable from a mobile terminal which has been designated a command terminal, using function 7. General status information for all system resources, including identification number and status code, can be obtained by keying ST. A 10-character area is reserved for the display of the status of each system resource, including the unit ID number and its current numerical status. This information appears for each mobile unit or other resource which is logged on the system. Reverse video (white background with black letters) is used to indicate available resources, and units on emergency status having a blinking display.

Messages to be delivered to the dispatcher display terminal by the terminal controller are held in a single queue. The queue discipline is first-in, first-out (FIFO). The next message to be displayed upon operator request is brought into the area of the CRT screen in which the operator is working.

The presence of a message in the queue is indicated by a "bell" tone, which repeats every 5 seconds as long as a message is in the queue. The tone repeat time is modifiable.

All messages to be delivered are queued except those which are responses to a request for general or detailed status. Those responses are returned immediately to the current working area, bypassing the message queue. Any input from the CRT terminal which occurs between receipt of a status request by the base station controller and its response is ignored.

Specifications

Display size	12" diagonal
Display area	Approximately 6×9"
Display format	25 lines of 80 characters each
Character size	Approximately 0.1×0.2"
Character set	224 displayable characters
	32 control codes (displayed in program entry mode only)
	64 upper case ASCII set
	32 lower case ASCII set (with descenders shifted down two scan lines)
	96 escape sequence control codes (displayed as detensified characters in program entry mode only)
	Upper case only 64 ASCII set switch selectable

Transmission rate	1,200 bits per second
Transmission mode	Full duplex
Data transmission	10 bits asynchronous
	8 bits synchronous (switch selection)
Parity	Even/non (asynchronous)
	Odd/non (synchronous)
Alarm	Audible "bell" tone
Dimensions	Display: 20" W × 15" H × 15" D
	Keyboard: 20" W × 3 1/2" H × 10" D
Weight	Display 25 lb
	Keyboard 10 lb
Polling	Address up to 95 terminals (sequence as defined)

3. The Dispatcher Status Monitor Terminal

The status monitor terminal is physically identical to the dispatcher display terminal, but the keyboard is not normally used. The CRT screen alone is used as a monitor by the dispatcher, and displays, on-line, the general status of all mobile units and other resources in the system.

General status information contains only each resource's number and numerical status. This information is updated automatically by the base station controller. Reverse video is used to indicate units available for assignment, and units on emergency status are represented by a blinking status identifier.

Since the dispatcher display and the status monitor terminals are identical, the status monitor can serve as a backup [illegible] other unit. The main value of the status monitor ter[illegible]hat it continuously displays status information [illegible] the need for status recall by the dispatcher.

4. The Base Station Line Printer

The printer is used for logging and documentation, programming assistance, and management information reporting. Normally the printer is located adjacent to the dispatcher's display console. It will produce an original document plus up to four carbon copies, and alternate character sets are available.

Specifications

Printing Rate:	
Characters	100 characters per second
Lines	60 lines per minute 150 lines per minute (short lines)
Input data code	7-bit ASCII, plus parity
Paper requirements	Standard sprocketed paper, produces up to four carbon copies
Printing structure	80 characters per line, 6 lines per inch
Character set	Full 64 ASCII characters
Dimensions	11" high, 20" deep, 20" wide
Weight	55 lb
Standard features	Audio alarm buzzer Paper memory control (10 sec)

5. The Mobile Terminal Line Printer

This optional attachment for the mobile terminal provides a hard copy output of the text displayed on the mobile terminal.

The mobile printer is a solid-state, silent-head printing device. Messages may be printed by remote control from the base station, or the mobile terminal operator may press the PRINT key on the terminal keyboard to obtain a copy of the text displayed. With remote control print, messages appear identical to data messages containing ordinary text. If the terminal operator desires printed copy, no retransmissions are required, since the printing is done directly from the terminal's memory.

Specifications

Print Speed	3½ lines per second, 16 characters per line
Print Time	4.5 seconds for a full 224-character message
Dimensions	10" long, 6" high, 5" wide
Mounting	Adjacent to and below the mobile terminal

APPENDIX C

LIST OF MANUFACTURERS OF MOBILE DIGITAL COMMUNICATIONS EQUIPMENT

Atlantic Research Corp.
5390 Cherokee Ave.
Alexandria, Va. 22314

Coded Communications Corp.
1620 Linda Vista Drive
San Marcos, Calif. 92069

Kustom Electronics
1010 W. Chestnut
Chanute, Kansas 66720

Motorola, Inc.
Schaumburg, Ill.

General Electric Co.
6350 LBJ Freeway, Suite 119A
Dallas, Texas 75240

Muirhead, Inc.
1101 Bristal Road
Mountainside, N. J. 07092

E – Systems, Inc.
P. O. Box 6118
Garland, Texas 75222

Sunrise Electronics
P. O. Box 163
Farmingdale, N. Y. 11735

APPENDIX D

HUNTINGTON BEACH POLICE DEPARTMENT COMPUTER-AIDED DISPATCH SYSTEM*

1. Introduction

The HBPD services a rapidly growing city in the Orange County metropolitan area of Southern California. Its population in 1973 was 150,000, approximately 10 times greater than its 1960 population. Huntington Beach has a large daily influx of people during the summer months, so that the population actually served by the Police Department may be double the number of residents. The city covers 27 square miles and has relatively few topographical features that impede communications with its mobile fleet of 22 units (average deployment).

The HBPD received 57,000 calls for service in 1973. Two dispatchers and one complaint board operator are normally on duty to handle these calls and control the mobile units.

2. Computer-Aided Dispatch and Mobile Digital Terminal System

Huntington Beach recently installed and placed in operation an advanced computer-aided dispatch (CAD) and mobile digital terminal system. This system has proved highly satisfactory in operation, and is described in some detail to acquaint the planner with its characteristics and capabilities. A scenario depicting the sequence of events and dispatch and status displays during an incident (in this case, an armed robbery) is presented to better illustrate the operational procedures of a CAD system. A layout of the facility is shown in Figure D-1; Figures D-2 - D-4 present details of the operator stations and microfiche unit.

The computer aided dispatch system consists of a computer and keyboard/CRT terminals which enter, store, and display information relating to the incident, the status of the mobile units, and actions taken by the dispatcher to service calls. Hard copy printers provide permanent records of all transactions.

The mobile units are equipped with Motorola MODAT digital terminals through which the officer can indicate his status: Available, Enroute, At Scene, Investigating, Returning to Station. Mobile teleprinters in the mobile units receive dispatches and other information normally relayed by voice. Patrolmen make all other transactions by voice. The MODAT unit is shown in Figure D-5.

When a citizen phones in a complaint, it is taken by a complaint operator, who types in data at a CRT/keyboard. The data enter the main computer, which creates an incident record for that incident. The address and intersection are sent via phone lines from the police computer to a central computer located at the city's Data Processing Department; the latter computer contains a geographic file, including beat number for the location. These data are sent back to the police department for display on the dispatcher CRT screen. The status of units assigned to the identified beat is displayed on another screen. The dispatcher assigns a unit, types the data into a computer, and notifies the unit by voice-radio. The computer simultaneously sends a digital message to the unit's teleprinter, giving dispatch data about the new incident and historical data obtained from the geographic file.

Each unit has a status terminal which permits the patrolman to send a change in status, via digital radio, to the police department computer. The computer maintains an up-to-date table of the status of each unit.

The HBPD has incorporated silent alarms into the CAD in a unique manner. If a silent alarm sends a signal to the police department, the computer sends a canned message of data and advice to the units assigned by the dispatcher. The Huntington Beach Police Department has linked its silent alarm system to the CAD and to a microfiche file. Alarms show up immediately on dispatcher consoles. In addition, the microfiche file contains location, interior and exterior layouts, aerial photos, locations of protection devices, and highway blockade positions of each alarmed site. A dispatcher can study the fiche display and guide a patrolman via portable radio to a particular location (see Figure D-4).

Requests for data base queries are given by voice-radio to the dispatcher by the mobile unit. The dispatcher enters the request (e.g., vehicle license number) by keyboard, and the police department's computer sends the request to the remote data bases. Responses from the data bases are displayed to the dispatcher, who relays the data to the mobile unit by voice-radio.

Operational data are captured by Huntington Beach for management reporting purposes. Currently, the daily logs of

*We wish to extend our appreciation to the personnel of the Huntington Beach Police Department for their assistance and cooperation in preparing this Appendix on computer-aided dispatch.

incidents are typed out automatically by the computer; however, detailed management reporting will not be placed in operation for about a year.

3. Radio System

The HBPD recently installed a UHF radio system consistent with the county-wide police radio plan (Orange County). The county allocates the frequencies for all police departments in accordance with a master frequency allocation plan. The police channels are in the 455 - 460 MHz range.

The channel assignments for the HBPD are shown in Table D-1. The Orange County communications net provides intra-county links and access to the California Law Enforcement Telecommunications System (CLETS). Through CLETS, data base queries can be directed to person wants and warrants, stolen vehicles and Department of Motor Vehicles files at Sacramento, and to NCIC and NLETS. The Orange County Criminal Justice Information System also can be accessed on this frequency.

One base station transmitter site is connected by land line to the command center. No satellite receivers or microwave links are employed. Five portable radios are used per shift.

4. Example of a Computer-Aided Dispatch

An example of a computer-aided dispatch was conducted by the HBPD to demonstrate the operational procedures they have developed to utilize this new capability, and to illustrate the sequence of CRT displays and formats used by the complaint board operator and dispatcher in handling the incident. The CRT displays are perhaps the most important feature of a computer-aided dispatch system because the operators enter and receive all necessary information from these displays; cards, status boards, conveyor belts, and other traditional dispatching aids are eliminated. All activity now focuses on the CRT displays.

All inputs to the CRTs must be entered via keyboards. Some information is entered by the operators as the incident is being handled; other information has been loaded into the data files prior to the incident and is recalled by the operators, or automatically by the computer if it relates to the current incident. In a sense, this procedure is a "new way to run the railroad," and requires some reorientation on the part of operations personnel.

The process of entering all data into the computer system via keyboards gives the CAD system a major advantage in that data relating to all incidents and field force operations (activities, times, allocations of forces, incident rates, and locational patterns) can be processed automatically by the computer and printed in convenient reports for use by operations and management personnel. Ultimately, CAD should contribute to more efficient use of manpower and mobile forces, enhanced officer safety, reduced workload on operations personnel, and better management reporting because of reduced clerical workload and time involved in statistical report preparation. The degree of the advantages offered by CAD systems has not been established because of the newness of the innovation, but the potential is evident.

The HBPD has identified a number of advantages offered by CAD, primarily relating to the reduced workload for entering and capturing data concerned with operations. These time reductions include:

(1) Recording incident response times
(2) Entering file numbers
(3) Typing radio logs
(4) Updating unit status
(5) Recording unit status
(6) Entering complaint information
(7) Transferring complaint data to dispatcher
(8) Sorting incidents by area and priority
(9) Patrol unit status change (by patrolmen)
(10) Writing dispatch information (by patrolmen)

Table D-1. HBPD Channel Assignments

Channel Name	Number	Use	Base Frequency, MHz
Green	1	Local voice channel (dispatching plus digital status)	Duplex, 460.1
Orange	2	Tactical frequency linking other departments in that part of Orange County	Duplex, 460.4 460.2
Blue	1	County: data file (provides link to state data files through CLETS)	Duplex, 460.5
White	1	Local car-to-car without repeater	Simplex, 465.3
Red	1	County: broadcast	Duplex, 460.025
	1	Digital (to teleprinter)	Simplex, 512.65

For these functions, CAD is estimated to require 550 man hours per year versus nearly 4000 man hours per year for the old manual system.

Before studying the sample incident shown in Figure D-7, the reader should review the CRT format definitions given in Figure D-6. Format (a) is available to the complaint board operator; formats (b) and (c) are displayed to the dispatcher. Each has a keyboard to enter data into the system with the aid of preset formats that are called up on the screen to minimize operator typing workload.

The sample computer-aided dispatch described in Figure D-7 simulates an armed robbery. The scenario focuses on the procedures used by the operations personnel in dispatching and controlling mobile units assigned to the incident.

In the command center, the *complaint operator* has one keyboard and display for entering the citizen's call for service. The *dispatcher* has a keyboard and two displays and operates a radio console. One display shows the *status* of the patrol fleet, the other has *variable formats* for incident summaries, and incident disposition and other special reports.

In Figure D-7, column 1 describes the events in the robbery and column 2 the complaint writer's activities. Column 3 shows the changes in the incident display screen as the event takes place. Column 4 describes the dispatcher's activities, and columns 5 and 6 show the dispatcher's status and incident screens. The manner in which information is entered and retrieved from the display screens by the operations personnel is clearly demonstrated by this scenario.

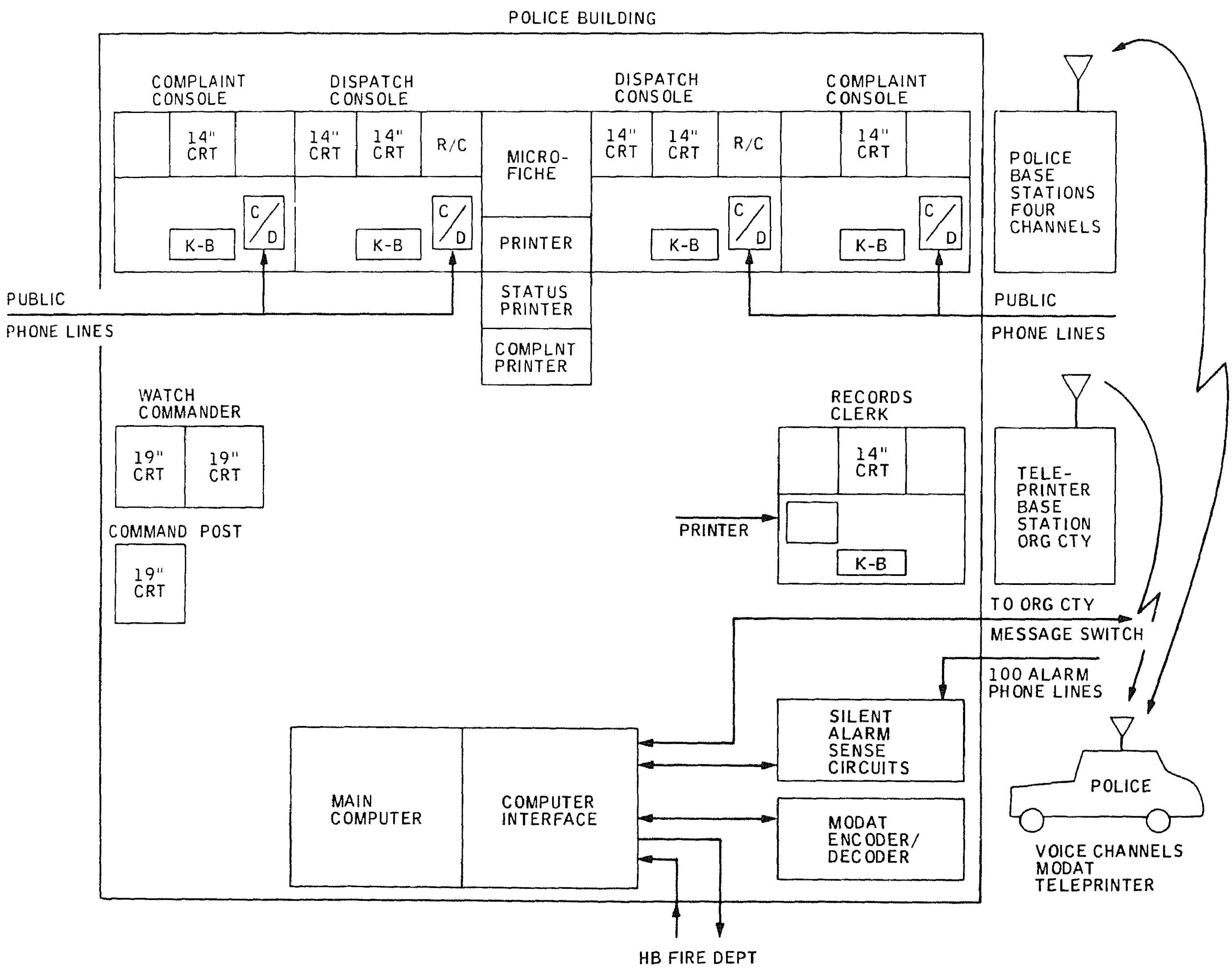

Fig. D-1. Huntington Beach Police radio system

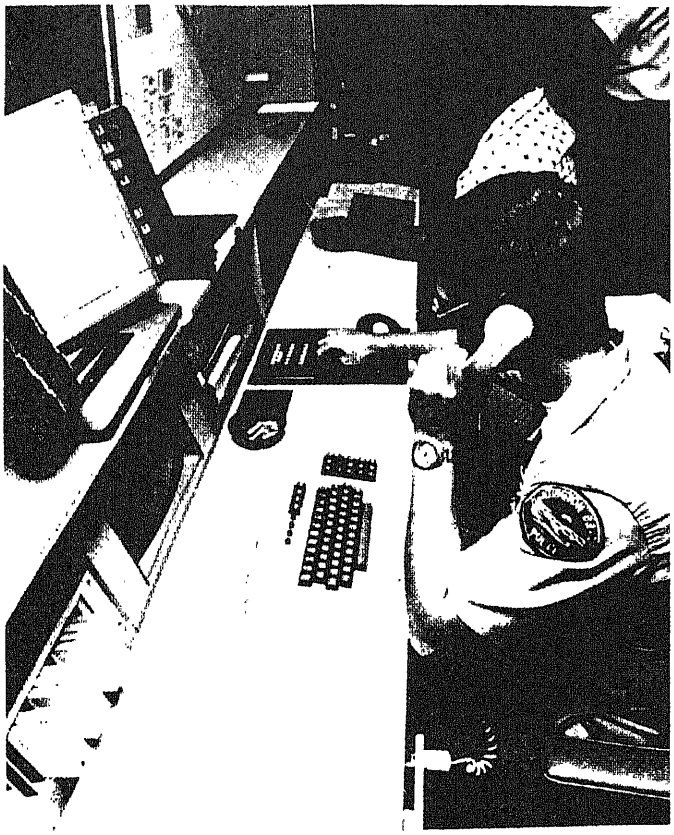

Fig. D-2. The HBPD command and control console

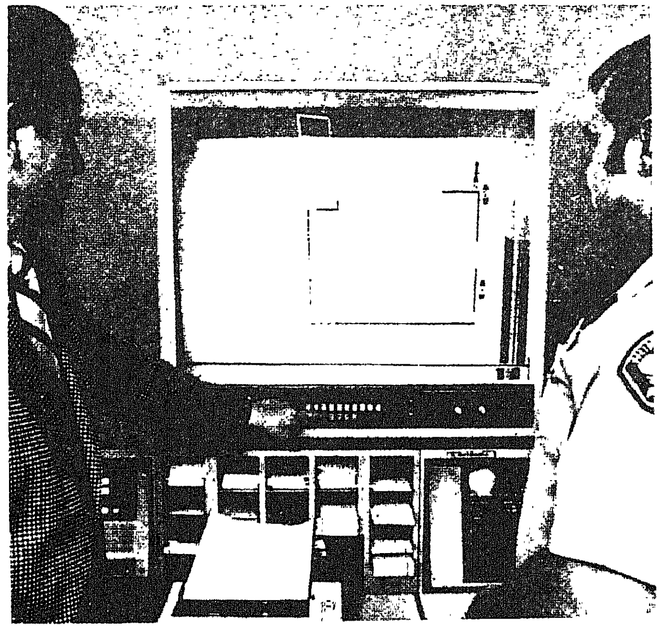

Fig. D-4. Microfiche data file

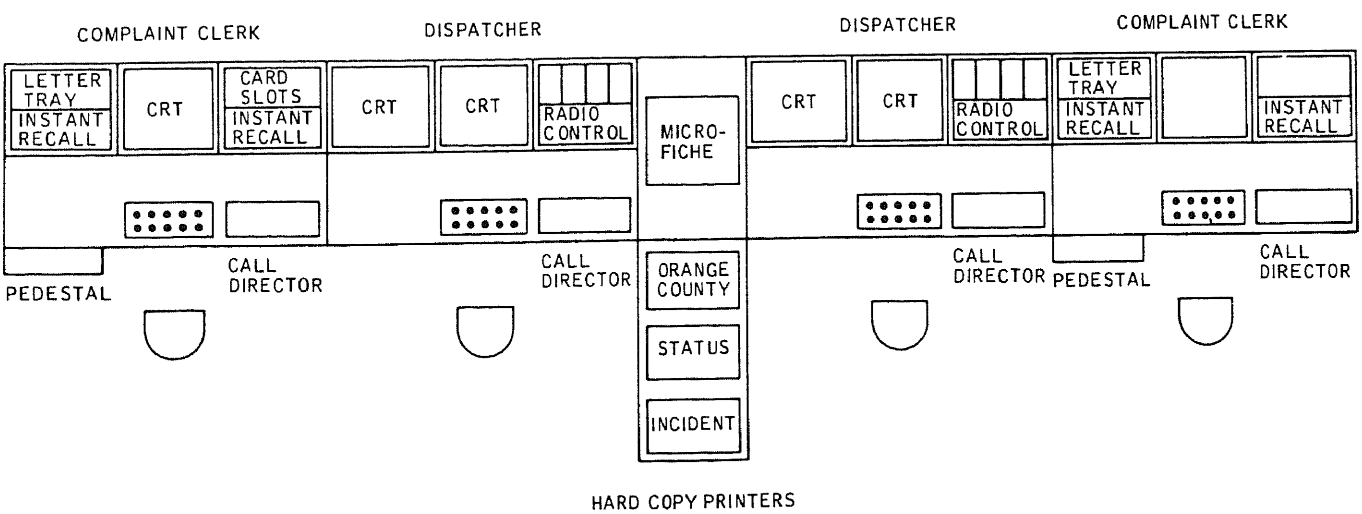

Fig. D-3. Console layout

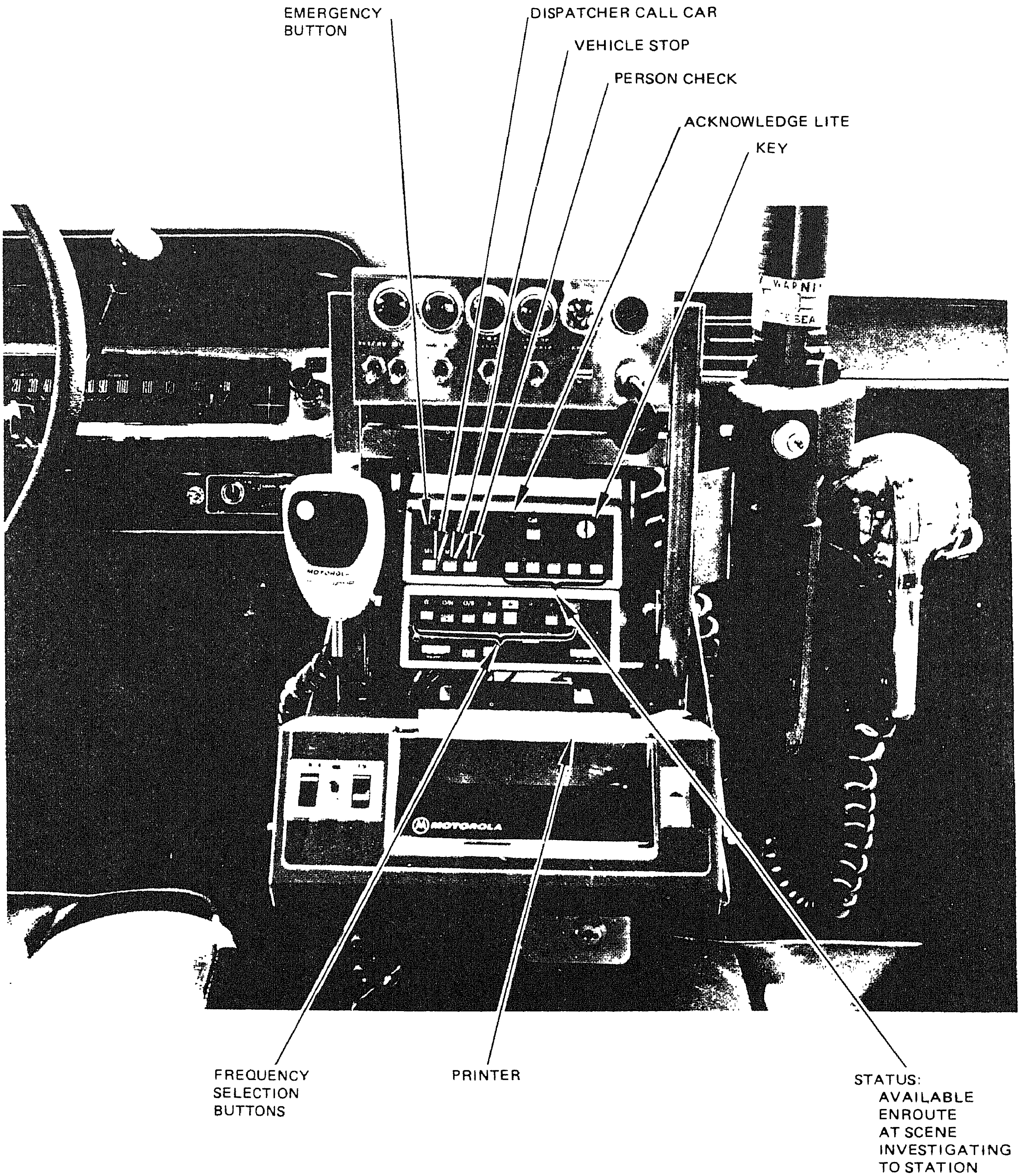

Fig. D-5. MODAT mobile digital terminal installation

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Lines 6-9 and 10-13
ıtry formats. Lines
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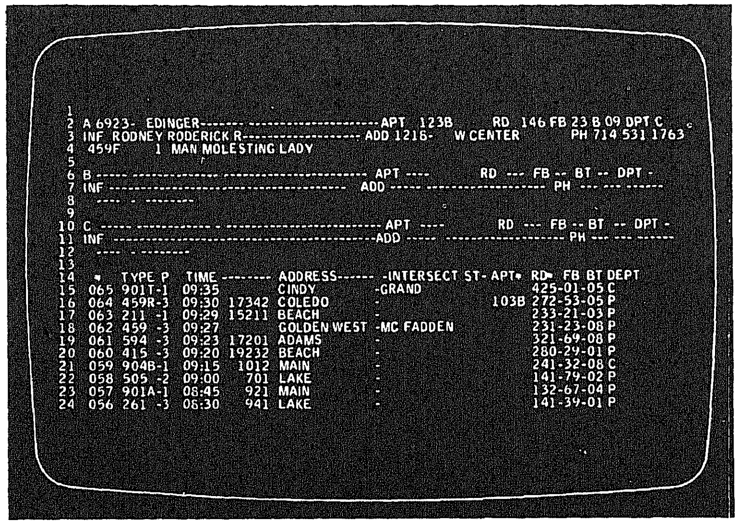

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nobile data system.
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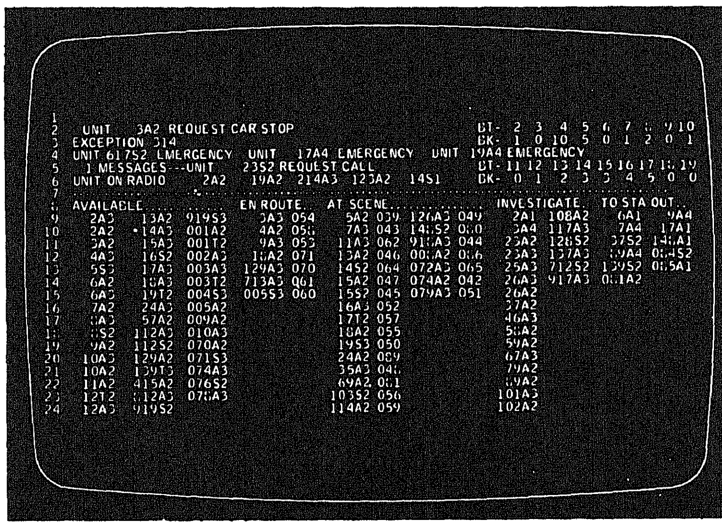

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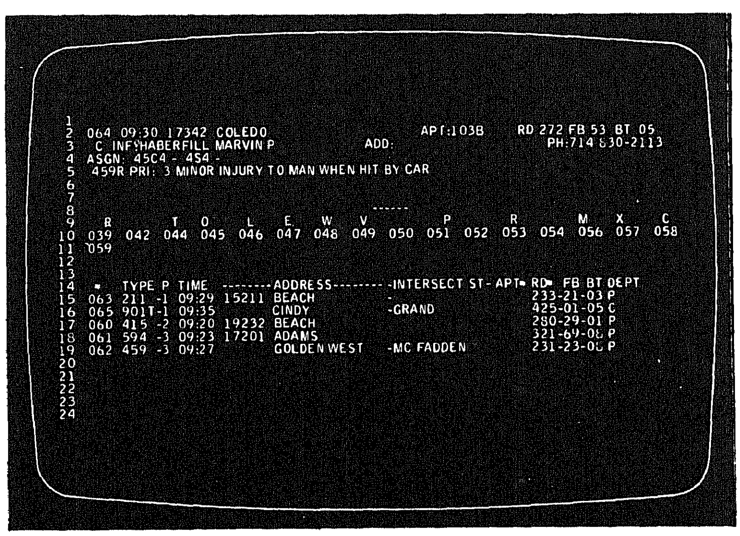


Fig. D-6. CRT display formats

APPENDIX E

RESULTS OF A FIELD TEST OF SEVERAL MOBILE DIGITAL TERMINALS

A field testing program was conducted in mid-1974 by one agency considering the introduction of MDTs in its patrol fleet. Results of this test program are summarized in this appendix to illustrate the accuracy of transmissions achieved in an urban area of varied communications environment, and to point out several operational features of the equipment that the field officers found particularly helpful (or objectionable). All tests were conducted using existing base stations with terminals provided by equipment manufacturers.

1. Accuracy Test Results

The results of the transmission accuracy tests are summarized in Figure E-1. Data are shown for four significant categories of results for both mobile-to-base and base-to-mobile transmissions. The first category indicates the overall percentage of test locations at which totally successful message reception occurred (i.e., one error-free, full-screen message received for each full-screen message transmitted). Category two shows the percentage of locations at which totally successful messages were received, but which required multiple transmissions, including: (1) re-transmission due to the receiver's failure to accept the message (low signal-to-noise, high error content, etc.), and (2) failure of the receiver's message-acknowledge signal to reach the transmitting terminal. The multiple transmissions require increased transmitter *ON* time per message. The third category presents the percentage of test locations at which messages containing errors were received; of the 55 error messages received, 31 were displayed as detected errors. The remaining category is the percentage of locations at which no full-screen message was received during the transmit cycle.

Of the 802 mobile-to-base and 833 base-to-mobile tests, full-screen message transmissions were accomplished successfully for 93.8 and 93.7 percent of the attempts, respectively. Approximately one-half of the error messages can be considered useful because of the high ratio of correct data to detected errors. Generally, the test results represent worst case conditions; with upgraded communications links, operational results should equal or exceed those observed during the test program.

Equipment features found to be helpful (or objectionable) are discussed in the following section.

2. Human/Operational Factors

The following comments were made regarding the operational features of the equipments tested.

Screen

The eight-line screen is a good feature, allowing officers to view an incoming message in its entirety. The large screen, however, increases the physical size of the MDT, aggravating the existing seat space problem. The placement of the larger terminal on the vehicle floorboard center hump restricts both driver and passenger mobility and access to the shotgun.

One-line screens provide relatively compact size and allow field officers access to the shotgun and radio equipment more easily, but present other problems. Primarily, it is difficult to determine if an incoming message is one or eight lines in length. An incoming eight-line message must be called up one line at a time by paging forward or backward. This is both time-consuming and awkward for field officers. In addition, when inputting information on the screen, officers experience difficulty in determining what line they are on at any given time.

A problem experienced by all terminals tested was screen washout during daylight. The keyboards (white and black keys) were glossy, resulting in light reflecting directly on the screen. One terminal equipped with a sunshade protector did not reduce the glare. During night operations the adjustable keyboard illuminator reflected off the keys and made them difficult to read.

Keyboard

The keys on the terminals were too small and too compact, often causing officers to strike two keys at the same time. The keys on one terminal were larger but even more compact, causing the same problem; this was alleviated to some extent by the terminal's deep concave wells. Its rows of keys were arranged in a stairstep design, also helping to minimize the problem.

Requiring two keys instead of one to call up a message is not a desirable feature.

Mounting Adjustments

None of the terminals tested provided the flexibility of adjustment to accommodate optimum screen viewing and keyboard access for both a one- and two-officer car operation.

Message Send/Receive

Terminals restricting field units to 64-character messages pose problems. To run a suspect for wants or warrants, the limited message length would require officers to send two transmissions instead of one.

The audible tone indicating that an incoming message has been received, and the word "message" displayed on the bottom line informing the officer that he has an incoming message in his buffer are likeable features. Terminals that place the incoming message directly on the screen, wiping out the existing display, are disruptive and present a privacy problem in that the officer may be out of his vehicle at the time. If a terminal emits a retransmit tone when a message has been transmitted and not received by the base station, the tone could be distractive if it cannot be turned off except by power disconnect.

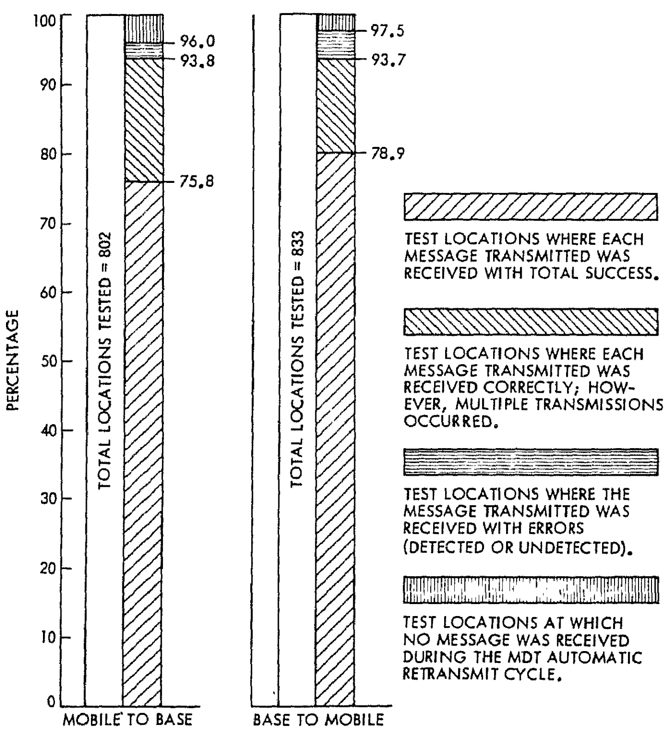


Fig. E-1. MDT test results

An automatic two-minute time-out feature that prevents a message from being continuously displayed, and requires a message being composed to be completed in less than two minutes is not desirable. Although the message can be recalled, it is disruptive to the officer. Also, when a message is being composed and has reached the last character, the terminal cannot go automatically to the next line. If the operator does not tab to the next line, the next character will type over the previously composed line.

An inability to clear the screen of the last message received from the base station is not desirable.

In some cases, indicator lights on the keyboard were not visible in the daytime.

Input Error Corrections

The full-cursor control capability on the large screen terminal (single space up, down, left, or right shifts) is a convenient feature. The cursor is easily identifiable and appears in the position of the next character to be composed. Without a cursor, all the displayed characters must be moved left or right, aligning the character to be corrected at the last character position.

Safety Padding of MDT

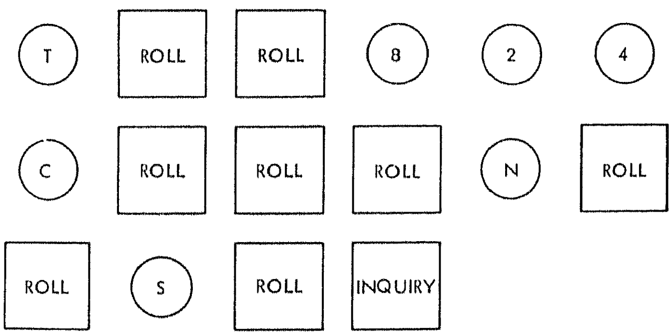
Not all terminals provide safety padding and rounded corners to protect an officer from injury in case of a traffic accident.

APPENDIX F

PORTABLE DIGITAL TERMINALS

In-car mobile digital terminals have been sufficiently successful to stimulate interest in hand-held battery-powered terminals to be carried by patrolmen not traveling in cars. These terminals would give patrolmen the same freedom with digital communications that their portable voice transceivers now give them with voice communications. The terminals would give direct access to information stored in law-enforcement data banks.

The Metropolitan Police Department of Washington, D.C., plans to test two portable digital terminal designs during the summer of 1975, emphasizing primarily the direct data file inquiry capability. Few details are available,. but the following data were provided. One terminal, produced by Electromagnetic Science Corp. of Chambree, Georgia, has a 16-character plasma display and 20 keys, and can store messages of 64 characters. It will be approximately 3½ x 8½ x 1½ inches in size, and will transmit digital messages over the GE PR-25 radio, which will also supply its power. The digital keyboard features multifunctional keys, as shown in Figure F-1. To run an inquiry on license number 824CNS, the officer transmits the following sequence:

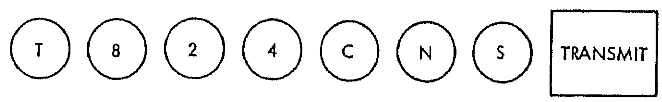


For out-of-state plates, he enters a two-letter state code before pressing "Inquiry."

Keyboard functions are controlled by software, and, by changing the programming, different functions can be assigned to the individual keys.

The Burroughs Corporation of Paoli, Pennsylvania, will produce a second type of portable terminal for the Metropolitan Police Department evaluation. This terminal will have a 32-character display and 42 keys; it can store messages of 32 characters. Its dimensions are approximately 9 x 5 x 2½ inches. It contains its own power supply but transmits via the GE PR-25 portable radio. The keyboard includes one key for each of the 26 letters and 10 digits, as well as function keys for: Backspace, Space (2), Transmit, Acknowledge, Clear, Shift, and Display (Turn on/off). It also has four light indicators.

To send an inquiry on license number 824CNS, the patrolman transmits the following sequence:



Both vendors anticipate that size reductions can be achieved in production runs of 1000 or more, and that unit costs will be considerably less than those of in-car terminals.

Portable terminals might find their way into police cars as replacements for the larger MDTs. They are smaller, and have the advantage that a single radio unit could replace combined units now in use: in-car voice radio, in-car MDT, and the voice portable radio.

Computer Science Corp. has been contracted to evaluate this program. Its findings will not be available before 1976.

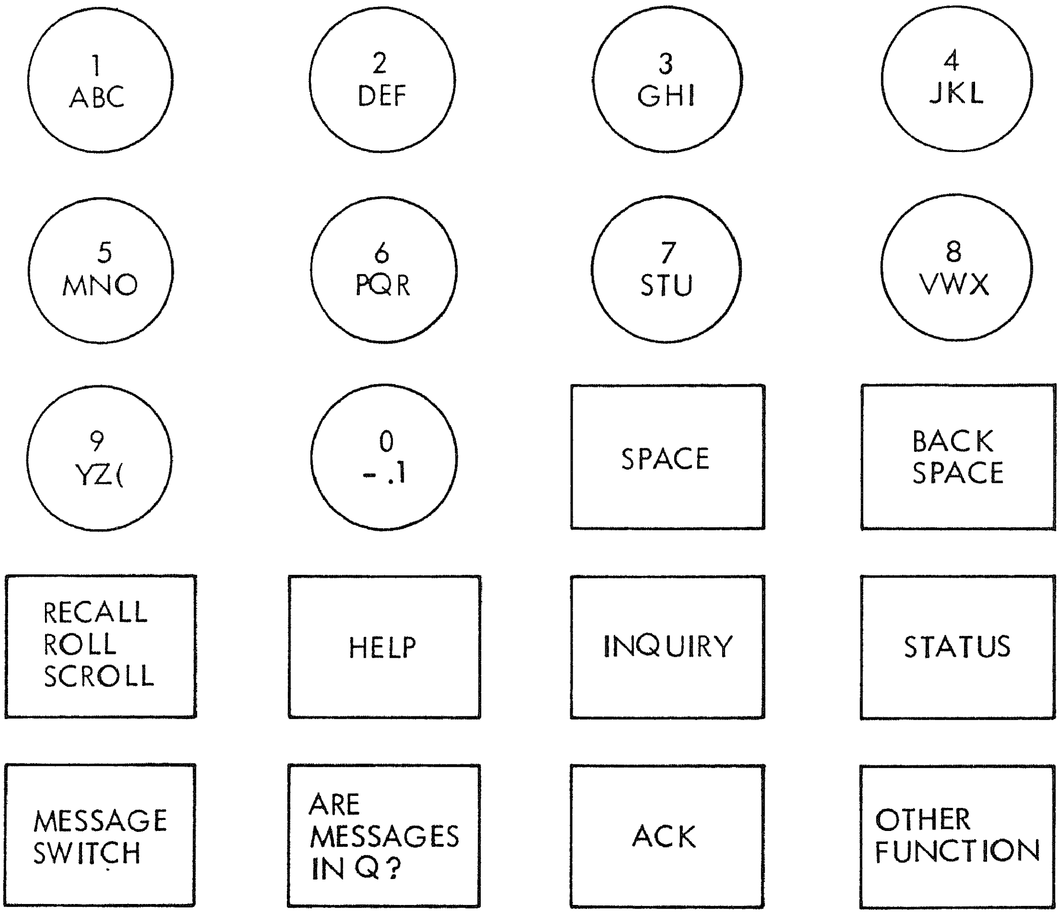


Fig. F-1. Digital keyboard for EMS portable radio

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